Geographic and Demographic Suitability of Cycling in North American Cities

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

With interest in cycling increasing in recent decades, local authorities and planners have been eager to enact policies to expedite a mode shift from driving to more sustainable, equitable and accessible transportation options. However, promoting cycling has encountered many challenges within car-dominated cities in North America. Previous research on the factors that influence cycling have cited geography-related concerns such as weather, elevation changes, and low land-use density as main reasons for not choosing to cycle (Pucher & Buehler, 2021). Similarly, it is understood that a city's demographics, particularly the age distribution and physical capacity of residents, may influence the likelihood to cycle.

This thesis discusses the geographic and demographic analysis of the suitability of cycling in four North American cities of various sizes, densities, geographies, and climate. Vancouver (BC) and Portland (OR), Waterloo (ON) and Madison (WI) are evaluated for their physical and demographic attributes that either promote or limit the propensity to cycle. The research then examines the planning responses in each city aimed at overcoming these challenges.

The results of the research reveal both positive and negative attributes. For example, Portland and Vancouver have much more conducive climate, while Waterloo and Madison have demographics (students) that have greater tendency to cycle. While variability exists in the physical and demographic attributes, the results demonstrate that those cities that have addressed their shortcomings have achieved greater cycling mode shares. The approaches and lessons learned from this work present a structure for cities to recognize their strengths, identify their weaknesses, and tailor the policies and investments to make cycling a more comfortable mode of transport for everyone – particularly those for whom physical or other limitations may present limiting factors.

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Chapter 1: Introduction

1.1 Background

The use of bicycles as a mode of transport in urban areas has been increasing in popularity in recent years due to the many personal and societal benefits derived from cycling compared to driving. Personal benefits for shifting from driving to cycling include reducing risk of chronic disease, improving mental health, and lowering household spending (S. Handy, 2020). Societal benefits for mode shift to cycling include reducing greenhouse gas emissions, improving public health, and developing local economies (S. Handy, 2020). Despite having many great personal and societal benefits, promoting cycling has been difficult, and continues to experience many challenges within car-dominated North American cities.

Promoting cycling as a viable transport mode is often most effective in influencing experienced cyclists because inexperienced riders face barriers posed by the physical elements of their city. Physical elements that often acts as barriers to stimulating interests to cycling include inclement weather, and the physical effort that is required particularly when traversing steep elevation changes, long travel distances from places of residence to access essential services, and underdeveloped infrastructure (Winters et al., 2011). Although some of the physical elements are natural and not easily changeable by humans (e.g., climate and topography), and some are changeable (e.g., the built environment and bicycle facilities) over various time scales – from the short-term (0-3 years) or longer (5-20 years)., cities will need to take a range of actions to overcome these barriers to make cycling a more viable option to travel.

One commonly suggested method to lower the barriers to cycling is to add new infrastructure. Although solutions that can overcome potential barriers to stimulating cycling interests are extensively developed around the world, the consideration of appropriate type of infrastructure that should be constructed and in which places of need often produces diverse responses depending on local conditions. The development of appropriate infrastructure in many North American cities is also further complicated by the cities' planning and development process that have historically supported the use of personal vehicles rather than bicycles (Newman et al., 2016). Because of this, modifications to urban streetscapes may not attract cyclists and may be seen as a detriment to car drivers.

In addition to building new cycling infrastructure, some cities experience fewer barriers to popularize cycling by simply benefiting from unique natural attributes that are found to be conducive to cycling (Winters et al., 2010). Some natural attributes of an ideal environment for cyclists include having flat topography; mild climate, with few days experiencing extreme temperatures; low precipitation (Pucher et al., 2021). A city with demographics that are comprised of cohorts whose ages and incomes are typically associated with higher rates of cycling was also found to be conducive to cycling as well (Pucher et al., 2021). Therefore, individuals are more likely to cycle when their cities contain one or several attributes that encourages experienced cyclists to cycle more often and invite new cyclists to travel by bike.

Conversely, individuals are less likely to cycle when cities contain few or no attributes that are conducive to cycling because these cities experience greater challenges in developing interest in cycling among their population. As an example, the Region of Waterloo in Ontario, a case study for this research, has struggled to attract meaningful mode shares by cycling at least in part due to its extended and extreme winter conditions.

This research then aims to formulate assumptions about the desirability of cycling in cities by understanding whether they contain the physical and demographic attributes that are found to be conducive to cycling. The physical attributes in consideration for the research include climate, topography, built environment, bike network connectivity, and demographics (Winters et al., 2011). Identifying whether each city possesses positive attributes for cycling can help explain in part the propensity to cycle in a city. The presence, or absence, of cycling-promoting features can be compared across similar cities to determine why they have disparate observed cycling mode shares for commuting activities. This thesis further examines how different rates of cycling among cities may be explained by the extent to which obstacles have been addressed within the planning activities of a municipality, or governments at other levels.

1.1.1 Introduction to the Case Study Cities

This thesis intends to question why the rates of cycling differ among four case study cities: two large cities – Vancouver, BC, and Portland, OR – and two smaller cities – Region of Waterloo, ON and Madison, WI. The exploration first examines the degree to which these cities have similar or dissimilar geographic and demographic characteristics. The choice of these locations is motivated by similarities among the cities; for example, Vancouver and Portland share similar Vancouver and Portland share similar physical, climatical, topographic, and demographic characteristics, as do Madison and Waterloo. Figure 1 introduces the case study cities including relevant population, cycling and land use data.

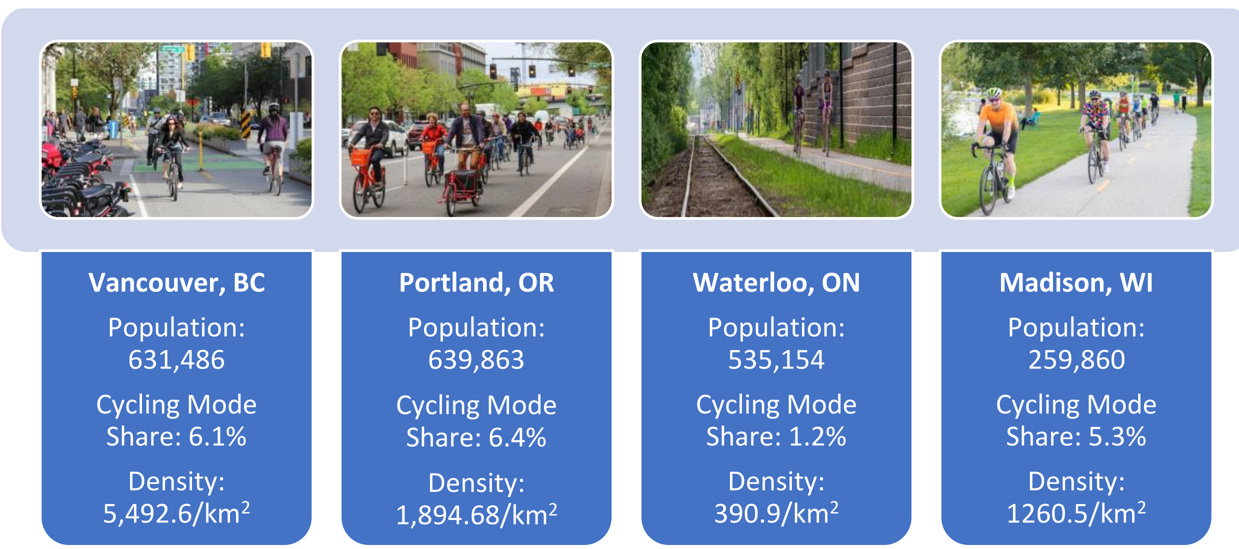


Figure 1 - Overview of Case Study Cities

While three out of the four cities selected for examination as a case study are single tiered municipality, Waterloo is the only case study city that is considered at a regional scale. The reason that the three most populous and urbanized municipalities of Waterloo region were selected for this research, instead of a single municipality, was because the urban centre of the Waterloo Region extends beyond the boundary of a municipality. Although the urban centres of both the City of Kitchener and City of Waterloo are in close proximity with each other, and are connected with the ION light rail line, the decision to include the City of Cambridge in this research was based on the fact that Cambridge has similar physical characteristics with Kitchener and Waterloo. With Cambridge being the second most populous municipality in the Waterloo Region, and having an extensive network of bicycle infrastructure, including Cambridge into the research can help to better understand the ability for cyclists to travel across this interconnected region. However, as the Region of Waterloo also includes several rural municipalities, they were excluded in the research because their cycling infrastructure is much less dense and the level of cycling activities is much lower. Including the statistics from the rural municipalities will result in a less balanced comparison with the more urbanized regional centres at the other case study cities.

1.1.2 Hypothesis

The hypothesis of this research – that the propensity to cycle is influenced by physical attributes and planning reactions – will be tested in two parts. The first step in the research is to evaluate the physical, geographic, and demographic features of each city and assess whether these attributes can be considered conducive or unfavourable to cycling. The results of this evaluation will then be examined relative to observed cycling rates for commuting purposes in each city to determine if the presence (or absence) of these attributes contribute to (or limit) cycling.

Second, the research seeks to understand if those cities that seem to be outperforming their expected cycling rates have achieved this outcome through planning that addresses directly the shortcoming identified in the first analysis. The review of bicycle planning documents and policy development history from each city will also inform this research as to the progress made by each city in stimulating the interests of new and current cyclists through responding to their physical attributes. Through gathering the results, this research will suggest potential reasons of why cycling rates are different between cities with similar characteristics and advise how each city overcame these challenges.

1.2 Topic Relevance and Implications for the Planning Field

Recently, there has been renewed interest in the planning field to research active transportation use and active transportation best practices because of the rise in popularity for cycling. This is especially the case as the number of people who cycle regularly for all trips has grown exponentially between the years of 1990 and 2016 in nearly all major North American and European cities (Pucher & Buehler, 2021). The increasing popularity of cycling has therefore led professionals in the planning field to develop more ways for cyclists to travel safely and influence them to continue cycling in the years onward. In light of the recent public health restrictions caused by the COVID-19 pandemic, it has become very difficult to ignore the lack of space given to active transportation users for them to travel comfortably on roads in North American cities (Dunning & Nurse, 2021). Fortunately, as some cities received positive public reactions from opening more spaces for active transportation users in urban areas, the policy will likely remain implemented for many cities even after health restrictions lift (Fischer & Winters, 2021). Because of the increased interest for cycling, further research will help planners decide on the best approaches to replicate the success as well as to stimulate and maintain interest for cycling that will guide long-term growth of active transportation use.

A considerable amount of academic literature has been published on the theme of active transportation. However, these research works have consistently shown that there is not a consensus on the best approaches to plan for cycling use and to stimulate cycling demand in the North American context. This is because the cities in which research works were conducted possess different physical attributes that encourage and discourage bicycle use. Forsyth & Krizek (2010) have demonstrated that solely adding infrastructure without considering other accompanying strategies will not lead to significant increases to the rate of cycling. Instead, the research by Moudon et al. (2005) makes the case that having streets that are welcoming to cyclists and a mixture of land uses to reduce typical travel distances will generate greater interest in cycling. However, previous studies of cycling use have not dealt with the effects that a combination of physical attributes in the city could have in encouraging bicycle use, and whether the governmental policies were able to address and overcome the challenges. Therefore, the findings of this research will make an important contribution to the field of transportation planning by advising how car-oriented North American cities can identify their physical attributes that promote or dissuade cycling and through purposeful planning interventions improve the attractiveness of cycling.

1.3 Research Questions

This research work is directed by the exploration of the following core questions:

- What are the geographic and demographic factors that are known to influence the rate of cycling – positively and negatively – in urban areas?
- To what degree are these attributes present or absent in the case study cities?
- To what extent does planning and design elements explain differences in the propensity to cycle among those cities with similar, or dissimilar, geographic features?

The first two research questions aim to determine the key features that makes individuals want or not want to cycle and how the physical attributes of each case study city been conducive to cycling use. Answering these questions within this research will improve the understanding of how each city performs in key features that encourage or discourage the use of cycling and forms the basis of comparison between the cities.

The third research question addresses why there is a disparity in cycling rates for commuting purposes between the case study cities – Vancouver, BC and Portland, OR; Waterloo, ON and Madison, WI – despite similarities in their geographic and demographic characteristics. The review of the physical attributes of each case study city will be important to determine the difference in policy responses and the awareness of opportunities and challenges to encourage both new and current cyclists to cycle frequently. Although the mode share of cycling for commuting purposes in North American cities remains low, as compared with other regions of the world, some cities have been successful in promoting cycling use in the recent decade and lessons from each case is invaluable for future expansion of cycling.

1.4 Thesis Structure

This thesis is organized into six chapters. Chapter one, the introduction, presents the background leading to this research topic and the purposes of this research, including the questions to be answered and the research structure. In chapter two, a review is conducted of relevant academic literature surrounding the factors influencing the use of cycling and the strategies for improvement. The third chapter explains the methods developed and applied to collect and analyze data surrounding each key attribute: built environment, topography, bicycle network connectivity and density, weather, and demographics. The next chapter then describes the results of the quantitative analysis to inform each city's level of suitability for cycling. Chapter five of the thesis summarizes a review of the cycling planning documents from each case study and assesses how well these cities have addressed those challenges identified in the attribute analysis. Lastly, responses to the research questions, recommendations for future developments of cycling in each city, and future research needs are discussed in the sixth and final chapter.

Chapter 2: Literature Review

This thesis sets out to understand how the physical attributes of cities influence the propensity to cycle for both new and current cyclists. Moreover, the thesis attempts to evaluate how planning processes have helped to address shortcomings in these physical attributes that have ultimately resulted in stronger-than-expected cycling mode share for commuting activities. To inform the methods used in this thesis, this chapter reviews the literature on the relationships between physical, geographic, climatological and demographic attributes of cities and the propensity to cycle for both new and current cyclists. The chapter also reviews planning responses that are intended to promote cycling in response to the cities' characteristics.

2.1 Introduction

Interest in research on methods that help car-oriented cities to promote cycling has been growing in recent decades because of the rise in popularity of cycling (Pucher & Buehler, 2017). Cycling has become an appealing mode of transport for an increasing number of people because of the many great health (Heath et al., 2006) and environmental (Chapman et al., 2018) benefits that cycling brings to the individual and society. The increased physical activity of individuals, gained through the use of cycling, contributes to reducing the risk of death from all causes (Heath et al., 2006). The replacement of trips facilitated by driving gas-powered vehicles with cycling also brings environmental benefits through improving air quality and resolving motor vehicle congestion (Chapman et al., 2018). As a result, local governments in places where cycling has not been popular have begun to realize the benefits to cycling and have taken steps to introduce cycling to their residents to build a healthy lifestyle and reduce carbon footprint. The steps by local governments to stimulate interest to cycle in their cities are often diverse (Furth, 2021)and not all cities have been successful. Researchers have yet to make conclusions about why.

Previous studies of active transportation have not explicitly examined the reasons why similar-sized cities may generate very different cycling mode shares. The disparity of the rate of cycling can be observed among North American cities where the economies are highly developed and most households own a car (Buehler & Pucher, 2021). Other possible explanations for a disparate rate of cycling includes the political determination of local governments to improve cycling experiences and the deterrents to cycling contained in each city's physical characteristics. Previous research has suggested that political will of local authorities to advance cycling infrastructure can have a significant effect on cycling mode share (Furth, 2021). However, questions about the role of each city's physical attributes in impacting cycling, and whether cities can be naturally more desirable for cycling, remain unanswered. Answers to these questions, which this literature review begins to do, can help planning practitioners understand whether some cities possess physical attributes that are advantageous to and result in greater cycling activity. Moreover, this literature review begins to identify best approaches to overcome the challenges to promoting cycling.

The purpose of this literature review is therefore to determine the physical attributes that are shown to have a positive and negative influences on the desirability of cycling. The review of literature can respond to the research goal by discovering the physical attributes that influence cycling and use the discoveries to formulate assumptions of the rates of cycling in each case study city. When differences exist between the expected and observed cycling rate for commuting activities, this research will also examine if the planning policies play a role in overcoming the challenges to promoting cycling. Therefore, the review of relevant literature will reveal insights about the major factors of stimulating cycling interests and help to inform how best to expand the use of cycling in North American cities in the future.

2.2 The Impact of Built Environment on the Desirability of Cycling

One of the physical attributes found to have a significant impact on the desirability of cycling is the built environment. Handy et al. (2002) define the built environment as an overarching term that considers multiple aspects of space including urban design, land use, and the physical infrastructure. When individuals form perceptions about the organization of the spaces that they travel through and interact with, the perceptions that they have are found to have influences over their willingness to travel by bike (Moudon et al., 2005). Surveys conducted by researchers have also reinforced the relationship between the perception of space at their destinations and willingness to cycle to access those spaces (Moudon et al., 2005). For example, neighbourhood centres that contain high density development and a mixture of land uses are found to attract cyclists, whereas places containing low density development with a single land use do not (Moudon et al., 2005). This result demonstrates the importance of having high-density and short distances between essential destinations to improve cycling convenience. This conclusion is also supported by work done by Heesch et al. (2015) whose research found that having short travel distances between places of residence and city centres, transport hubs, or essential services will tend to have high cycling use.

Although planning scholars have understood the relationship between the built environment and the desirability of cycling, questions regarding why the historical process of urban development did not create places that are more conducive to cycling remain unanswered.

Research on the historic process of designing cities can help with understanding why planners have not typically prioritized cycling use resulting in disparate rates of cycling in cities. With many urban areas of North American cities containing spaces that are dominated by cars, it is important to then reflect on the rationale for why such places were designed in the first place. One attempt to answer this question is from Newman et al. (2016) who discussed theory of urban fabrics and explained the evolution of cities to support the dominant transportation modes at each time period. In North American cities, the dominant transportation mode evolved over time, beginning with walking, then mass transit, and more recently the automobile; the introduction of each mode brought great changes to the way cities were planned (Newman et al., 2016). This is evident in U.S. cities that were developed prior to the widespread introduction of the automobile. Boston, New York, Philadelphia and other cities all have compact, high-density built environments, particularly in their urban cores. These can be contrasted with cities such as Los Angeles, Calgary and others where the development coincided with the wide adoption of the automobile, and a planning philosophy that nearly all future travel would be completed by motorized vehicles, eliminating the need for walking, cycling and other active modes.

More recently, as cities begin to realize the benefits of cycling, and become committed to reduce dependency on cars, city planners have made efforts to reorganize their urban spaces to make cycling a desirable transport mode. Approaches used around the world to reorganize urban spaces to be more accommodating to cyclists have been diverse; different types of design tend to produce various rates of cycling. Building on historic approaches, many cities have encouraged increases in the presence of high density land uses that have been found to be conducive to cycling (Christiansen et al., 2016; Koohsari et al., 2020). With these spaces containing a high concentration of diverse jobs and services, as well as residential units, people residing or working in these locations tend to have short distances to most destinations to which they needed access (Christiansen et al., 2016; Koohsari et al., 2020). The examples presented in the research by both Christiansen et al. (2016) and Koohsari et al. (2020) in different contexts around the world have presented similar outcomes that suggest that high density mixed use places are desirable places for people to cycle.

Methodologically, there are questions on the best way to assess the suitability of the built environment for cycling. Density is the most commonly used variable; one can measure population density (number of residents per unit of area) or employment density (number of jobs per unit of area). However, for transportation analysis, another common approach that is used to evaluate the density of urban spaces is the intersection density, which is calculated by counting the number of intersections within a given area. Typically, population and employment densities vary proportionally with intersection densities. Winters et al. (2010) explains that places with a high intersection density tend to have a higher propensity to cycle. As such, intersection density can be used as a convenient and easily-calculated metric to estimate the density of urban development and, by extension, the propensity to cycle in these areas.

Naturally, intersection density is a surrogate measure for the ease and convenience of accessing necessary activities and destinations. As intersection density increases, the distance traveled and travel time both decreases. Some authors attempt to measure the accessibility of areas through a concept of cost, which allows for elements such as time and effort to be measured in the same constructs as actual, out of pocket expenses. This gives rise to several observations on the relative cost of travel by different modes, particularly a comparison between motorized vehicles and cycling.

Although driving tends to be the quickest method for people to travel to their destination, in North American cities, this mode is often not available to everyone because of high costs and age restrictions. As cycling tend to have a low start-up cost, and no age restrictions, the cost to travel by bicycle could certainly be lower than driving in some circumstances. However, competition often arises between using different transport modes because users often face different restrictions and costs (such as start-up and time loss).

Heesch et al. (2015) suggest that cycling can be more competitive than driving if the travel distance is less than 5 kilometres. Even though the ideal for cycling is for places of residence and services to be within 5 kilometres of each other, the large car-oriented neighbourhoods surrounding North American cities can make implementing this ideal very challenging. Because of this, Bertolini and Le Clercq (2003) suggest planners use the tools available, including land use zoning and transportation network analysis, to increase the competitiveness of cycling in comparison with driving. When considering the effects that the built environment has on the desirability of cycling, the research by Koohsari et al. (2019) has also demonstrated that high-density, mixed-use built environments tend to create conditions with a higher propensity to cycle. Similarly, high density and highly diverse land uses such as those found in activity centres – locations where a high concentration of diverse jobs and services are located – can also increase the likelihood of cycling (Christiansen et al., 2016). With multiple research outputs in different contexts suggesting that there exists a relationship between building density and diversity of land-uses and the likelihood of cycling, this attribute is one that will be used to measure the case study cities' physical attributes and their influence on cycling.

2.3 The Impact of Topography on the Desirability of Cycling

Another attribute that was found to have significant impact on the desirability of cycling is the topographic variations of a city. As cycling is a mode of travel that requires varying levels of physical effort from individual cyclists to operate the vehicle, the rate of cycling activity becomes difficult to improve if a high variation of elevation exists, particularly along cycling routes (Li et al., 2012). The impacts for cyclists become significant when traveling to destinations where professional activities, work for example, take place. In addition to the effects of the cyclists' appearance, the topography also impacts the cyclist's comfort when they're required to travel on steep slopes for their journey (Li et al., 2012). With comfort being a major factor in motivating individuals to cycle (Winters et al., 2011), the opportunity to promote cycling will increase in cities that are predominantly flat and present fewer, steep grades (Li et al., 2012).

The topography along a cyclist's route can create a barrier to cycling by requiring them to possess a sufficient level of physical ability to traverse the slopes they experience. Especially in cities with great topographical variations, the likelihood of a cyclist experiencing a steep slope along a journey often increases. The presence of steep slopes thus makes cycling a travel mode that does not suit all ages and abilities. As such, the challenge in topography makes meeting the cities' goal of increasing the cycling rate difficult. Winters et al. (2011) conducted a survey of cyclists about the key factors influencing their choice to cycle, and the results of the survey reaffirmed that the presence of a steep slope will negatively impact respondents' decision to cycle. Although both Li et al. (2012) and Winters et al. (2011) did not outline the specific metrics of a steep slope that deters cycling, the degree of slopes that could be perceived as too steep for travel will vary between cyclists with different physical ability.

The increase in the cyclists' travel time to reach their destinations induced from the topographic changes is also a major factor limiting the attractiveness of cycling as a travel mode. Because cyclists require more physical effort to maintain the same speed on an uphill slope as on flat areas, travel time and efforts tend to increase if a cyclist's journey involves traversing steep slopes. Rodríguez & Joo (2004) discovered that the increase in travel time associated with the local topography significantly reduce the willingness for people to travel by bike. As an increase in travel time will result in the individual's valuable time taken away from the time to be spent at their destination, a prolonged journey on steep slopes could require cyclists to perceive the journey as incurring a higher cost.

The results from multiple previous research efforts demonstrated a common agreement that the topography of a city poses a significant barrier for people to be persuaded to cycle. The impact is especially significant in cities that contains bicycle routes that involve prolonged sections of high elevation changes. This type of city tends to be limited in the types of trip that can be completed by bike due to reduced comfort and increased travel times (Li et al., 2012; Rodríguez & Joo, 2004; Winters et al., 2011). What remains unanswered is the degree to which the slope that cyclists face will dissuade them from cycling. The topic of topography requires additional study to accurately understand the magnitude of impact it has on the desirability of cycling as a transport mode for both new and current cyclists.

2.4 The Impact of the Bicycle Network to the Desirability of Cycling

The characteristics of a city's bicycle network also influence the desirability of cycling depending on the quality of the infrastructure that cyclists experience on their journey. The types of cycling infrastructure typically constructed in North American cities include off-street pathways dedicated for cyclists, off-street multiuse pathways shared between cyclists and pedestrians, on-street protected bicycle lanes, on-street painted bicycle lanes, and shared traffic between cyclists and motorists (Furth, 2021). All types of cycling infrastructure can produce different perceptions of comfort for cyclists because each type offers a different level of separation with other road users, such as motorists and pedestrians. Because high differences in speed and high traffic volumes on a shared roadway often create greater risks (or greater perceptions of risk), especially collisions between the road users, these facilities may be a deterrent for cyclists, particularly new cyclists. Therefore, the ideal type of cycling facility where cyclists often feel the most comfortable are cycling lanes that are separated between road users and even more so in facilities that are separated by barriers (Furth, 2021).

When cycling infrastructure is absent for substantial portions of high potential demand routes, many potential cyclists may be deterred because they perceive danger. As cycling infrastructure constitutes more than a series of disconnected links, a well-designed bicycle system will have infrastructure that collectively forms a network that allows for safe, direct connections between high volume origins and destinations (Furth, 2021). When gaps exist in the connections between new and existing infrastructure elements, the results can be a significant reduction in the desirability of cycling for transport. Therefore, the evaluation of bicycle network's impact on the desirability of cycling involves a wide range of considerations that help to understand the qualities of a good cycling network.

The evaluation of bicycle network connectivity involves determining the ability of cyclists to travel on an interrupted set of adequate facilities between their origins and destinations. Although the ideal scenario is for cyclists to be able to reach their destinations by solely traveling on dedicated cycling facilities, gaps may exist within cycling networks that tend to present cyclists with a difficult choice: continue on the shortest path where the cyclist's comfort level will be lower or to choose an alternative route that requires longer-than-minimum distances. While the safety of using the cycling facilities is often the greatest concern of cyclists, emphasis should also be given to understand the connectivity of the facilities to maximize the extent of safe cycling routes (Sallis et al., 2013). Especially given that cycling is often in competition with the convenience of driving in North American cities, the lack of direct routes for users to cycle to their destination may place cycling at a disadvantage relative to cars.

Furth (2021) has also discussed a similar need to develop cycling networks that maximize direct connections between origins and destinations to limit route detours to less than 20% of the entire route. Because cycling is a human-powered mode of transportation, the requirement to travel additional distances to remain in safe facilities will make the choice of cycling less desirable. The presence of facilities that create the perception of safety along the route may motivate more people to cycle. Therefore, this research evaluates the level of connectivity of cycling networks to determine the ability of cyclists to travel to their destination by only using the cycling network.

In addition to the considerations of the connectivity of cycling routes, the evaluation of bicycle networks also requires the considerations to the safety of users on the facilities. Sallis et al. (2013) found through a survey of bike owners that while 71% of the respondents shared that they have ready access to a bicycle, 60% of them did not bike in the past year, mostly due to reasons surrounding safety of their journey. With safety being found as a great concern for most potential cyclists, and with knowledge of what types of facilities are considered safe, more research is necessary to understand the impact of the presence of safe cycling facilities on the willingness to cycle.

Most researchers consider the connectivity of the overall bicycle network as a key indicator for the desirability of cycling (Buehler & Dill, 2016). They also agree that the density of bicycle infrastructure positively correlates to the decision to cycle (Buehler & Dill, 2016). When cyclists have greater access to high quality cycling facilities, the desirability of using a bicycle for the trip is significantly higher than in areas with low density of available cycling facilities. Given these observations, this research also investigates the density of bicycle facilities in each case study city to understand the desirability of cycling.

Beyond the density of cycling facilities, prior research also outlined a possible link between the density of street intersections and the likelihood of cycling. Winters et al. (2010) used intersection density as an indicator to compare decisions of mode choice between driving and cycling. The results of the research found that having high intersection density along the cyclists' route corresponded to a high likelihood of cycling (Winters et al., 2010). The authors observed that a high number of intersections leads to an increased number of possible routes for cyclists. However, a high density of street intersections can also increase the risk for cyclists to be involved in a collision with automobile (Wei & Lovegrove, 2013). Therefore, intersection density has been shown to be a metric that can both negatively and positively correlated to observed cycling activities.

2.5 The Impact of Climate on the Desirability of Cycling

Since cycling is a mode of transportation that involves travelling in outdoor uncovered spaces, the desirability of cycling is likely influenced by weather patterns. More specifically, the desirability of cycling can fluctuate with decreasing cycling activity as a result of extreme warmth and cold temperatures, as well as increasing levels of precipitation (Pucher et al., 2021). Böcker & Thorsson (2014) discovered similar observations in reviewing the rate of cycling activities across different temperature in the Netherlands. Their data suggest that the rate of cycling activities: tends to be low when the temperature is below 5 degrees Celsius; increases linearly when the temperature is between 5 and 25 degrees Celsius; and falls again when the temperature is above 25 degrees Celsius (Böcker & Thorsson, 2014).

Similarly, in the context of North American cities, Spencer et al. (2013) discovered that extreme cold temperatures in winter may impact the desirability of cycling. In their work, respondents indicated that they had a threshold temperature below which they opted not to cycle. While the lowest temperature that cyclists found comfortable differed from person to person, there were common strategies to addressing low temperatures, most notably having more layers of clothing. Still, in both the Dutch and North American cases, decisions to cycle are often made with the consideration of other environmental factors.

The desirability to cycle is also often influenced by the amount of precipitation. As Böcker & Thorsson (2014) suggested in their research, the willingness to cycling drops significantly when it rains or snows, and continues to decrease linearly as the precipitation intensifies. Motoaki & Daziano (2015) also found similar decreases in the demand for cycling when it is raining or snowing. Snowfall, however, was found to be a greater deterrent to cycling than rain due to the need for snow removal services to maintain the road (Spencer et al., 2013). Based on these previous findings, the case study cities will be evaluated for their climatic trends – temperature and precipitation rates – when evaluating their suitability for cycling.

2.6 The Impact of Demographics on the Desirability of Cycling

Another key feature that affects a city's ability to motivate increased cycling use is the age profile of residents. Previous research identified some demographic attributes that are positively correlated to the likelihood of cycling. In a survey of cyclists in Vancouver, Winters et al. (2010) found that there are five times more cyclists who are within the 19 to 25 age group than individuals who are aged 65 and above. As cycling is a mode of transport that demands physical abilities from individuals, and youths are generally more physically active than other age groups, cities with a high youth population may have greater potential to increase cycling activity (Winters et al., 2010). Similar trends were also observed by Buehler & Pucher (2021). Their research across multiple countries observed that cycle rates are substantively higher for those younger than 39 years old. In the United States, Chaney et al. (2014) surveyed a group of college students and discovered that 78% of respondents used active transportation modes at least once in a week, which is higher than the national average for other age groups (Chaney et al., 2014). Based on these observations, this research begins with the assumption that cities with a high proportion of youth residents and college students have the greatest potential for increasing cycling rates.

2.7 The Impact of Planning Policies on the Desirability of Cycling

The above sections identified the key elements of cities that can either be helpful in motivating increases in cycling – by attracting new cyclists or expanding the mode share of current cyclists. The literature also suggests that some cities have natural attributes – topography, climate and demography most notably – that may have negative impacts on cycling. Planning as a discipline and practice intends to achieve socially desirable outcomes through available tools and techniques. As such, it is appropriate to ask if there are planning interventions that have been successfully developed and implemented to address specific obstacles to cycling including those identified through this analysis.

With cars continuing to be the most popular mode of transport in North American cities, the level of ambition shown in each city's policies to influence a behavioural change to sustainable modes of transport can certainly influence the rate of cycling. One example of expanding bicycle use through policy interventions can be observed in Portland, Oregon. While Portland was historically a car-centric city, the local government began aggressively developing a series of interconnected bicycle boulevards beginning in the late 1980s to stimulate interest in cycling (Geller & Marques, 2021). Portland's decision to take substantive action towards building bicycle facilities was fortified as a result of the Complete Streets Legislation in the state of Oregon. Municipal governments were mandated to invest in cycling and walking infrastructure; concurrently, strong political leaders, who recognize the importance of improving cycling infrastructure, rose to power (Geller & Marques, 2021). In addition, the high density road layout of Portland contributed to Portland's success in building cycling facilities rapidly (Geller & Marques, 2021). Despite Portland's historic challenges stemming from its car-oriented urban design, the development of strong active transportation planning policies demonstrates the ability to successfully stimulate interest in cycling.

More generally, places where cycling activities substantial increase are in fact in places where their local authorities enacted robust plans and policies to influence bicycle use (Pucher et al., 2011). Although the intentions of city-wide policies are to improve the use of cycling in general, different policies are required to support cyclists who ride for utilitarian and recreational purposes. These groups tend to have different levels of confidence in their abilities in cycling and tolerance of discomfort; therefore, the plans and policies created also should consider the different needs to meet these users' respective goals. The challenge of attracting more utilitarian cyclists is even more pronounced in suburban areas in North American cities, given their dispersed land uses (McAndrews et al., 2018). In conclusion, different approaches to motivate increased cycling usage are required depending on the type of cyclists the policies seek to attract and the location on which the policies are enacted.

A final step in this research is to evaluate how the case study cities have addressed barriers to cycling. This is accomplished through a review of recent cycling planning documents with special attention to the other elements identified here.

2.8 Summary

This literature review presented many of the key factors that influence the desirability of cycling as identified through prior research. Obviously, much has changed surrounding transportation behavior in the presence of the global pandemic. Although the transportation habits of urban dwellers in many North American cities have changed significantly, the research into the key factors that influence transportation mode choice will continue to have its importance when cities continue their mission to reduce reliance on cars. The following table summarizes the primary lessons learned through the literature review. These relationships between city attributes and the opportunities or challenges associated with increasing cycling form the foundation of the methods used in this research, described in Chapter 3.

Table 1 - Summary of Lessons Learned

Attributes	Lessons Learned – attributes that motivate increased cycling
Built Environment	• Short travel distances to essential services (Heesch et al., 2015; Moudon et al., 2005) • Bicycle-oriented design (Newman et al., 2016) • Mixture of land uses (Christiansen et al., 2016; Koohsari et al., 2020) • High density of population (Christiansen et al., 2016; Koohsari et al., 2020)
Topography	• Low to no slope (Li et al., 2012; Rodríguez & Joo, 2004; Winters et al., 2011)
Bicycle Network	• Direct connections between origins and destinations (Furth, 2021) • High connectivity within the cycling network (Sallis et al., 2013) • Density of cycling network (Buehler & Dill, 2016) • Highly connected streets (Winters et al., 2010)
Climate	• Low precipitation or snowfall (Böcker & Thorsson, 2014; Motoaki & Daziano, 2015; Spencer et al., 2013) • Temperature between 5 to 25 degrees Celsius (Böcker & Thorsson, 2014)
Demographics	• Presence of college students (Chaney et al., 2014) • High population under 39 years old (Buehler & Pucher, 2021)

Chapter 3: Methods

3.1 Introduction to Methods

Scholars in the planning field have identified diverse research approaches to determine the suitability of cycling in a city. Previous research works used approaches including the evaluation of circumstances that influence individual perceptions on cycling (Winters et al., 2011), determination of features of a high-quality cycling space (Furth, 2021), and an examination of the policy responses that were proven to be able to stimulate cycling demand (Pucher et al., 2011). Although the previous research work forms a foundation of understanding about how to create an environment suitable for cycling, it is still undetermined whether the findings can imply that cities can be naturally more advantageous to promoting cycling. To address the deficit of knowledge in understanding the suitability of cycling in cities, this research compares and evaluates environmental, geographic, and demographic attributes within each case study city that were found through previous literature to influence cycling use. The comparison of characteristics across each case study city will help inform the degree to which there is a natural propensity to cycle in the case study cities and whether their physical characteristics played a role in their success in stimulating interest in cycling.

Because the environmental, geographic, and demographic attributes are often represented in both qualitative and quantitative forms, using the same metrics to compare between each retrieved variable is not a suitable method. Instead, this research uses the Multiple Account Evaluation (MAE) – a widely used tool (Region of Waterloo, 2009) for infrastructure assessment that allows for the inclusion and comparison of qualitative and quantitative results – to make it possible to determine if cities are naturally more advantageous in promoting cycling. The quantitative and qualitative data results will be compared using different metrics determined by known values and previous research works.

The method is applied to cities in North America (Vancouver, BC, Portland, OR, Waterloo, ON, and Madison, WI) that were purposefully selected based on their similarities and differences in the attributes identified as influencing the propensity to cycle. The MAE evaluation model allows for an effective comparison of the impacts of each physical characteristic because appropriate metrics – both quantitative spatial analysis and qualitative policy reviews – can be compared equally and directly in terms of their impacts on motivation to cycle.

3.2 Introduction to Multiple Account Evaluation (MAE)

Multiple account evaluation (MAE) is an assessment tool used for comparing multiple criteria for infrastructure projects and plans. This method aims to provide a balanced view for decision makers about the potential impacts that projects may achieve by accommodating comparisons between quantitative and qualitative findings (Region of Waterloo, 2009). With the physical attributes supporting and dissuading cycling use being represented by both qualitative and quantitative data, comparing the data using the MAE tool can standardize the methods of comparison and make it easier to draw conclusions. The MAE tool also makes comparing between the attributes simpler by allowing different sets of metrics to evaluate each physical attribute.

As described in earlier sections, the propensity to cycle has been shown to be influenced by various physical, climatic, demographic, and governance attributes. For this research, the six attributes to be compared using the MAE tool are:

- Built Environment

- Topography
- Bike Network Connectivity and Length
- Climate
- Demographics
- Policy Responses

The results generated by the MAE tool help with the evaluation of how physical attributes and policy responses of each city have been supportive of cycling. The metrics to evaluate cities' physical attributes and their influence on environments that are suitable for cycling are based on previous research work on each attribute. The policy responses will also be compared and evaluated through their ability to implement known best practices and process of overcoming challenges.

3.3 Quantitative Analysis

Many of the physical attributes found to be conducive or dissuasive to cycling are often represented quantitatively through data extractions. These analyses typically require spatial data; for this work, data were collected from government open sources and the University of Waterloo's data library, as well as statistical data collected from census administrators and meteorological agencies. Specific data gathering methods and calculations are explained in this section for each of the five accounts.

3.3.1 Built Environment Account

As described in the literature review, a critical variable that influences the likelihood to cycle is density. Some metrics of density include population or employment density, measured as the quantity of interest (residents or jobs) per unit of area, typically in square kilometres. Another commonly used density metric is intersection density, or the number of intersections per square kilometre. The relationship between the density of activities and intersection density is as one would expect: high land-use density areas in cities produce a greater number of intersecting roads, whereas low land use density (e.g., suburbs and rural areas) contain fewer intersections. Thus, summarizing the number of intersections within a specified area helps to differentiate between areas with different built form.

In this research, the density of intersections is calculated using spatial analysis tools for each of the case study cities (Vancouver, BC, Portland, OR, Waterloo, ON, and Madison, WI). The general approach is to overlay the city with a regular grid, in this case with hexagons with common, 1 square kilometer areas, and to count the number of intersections present within each cell of the grid. From these spatial observations, standard descriptive statistics can be calculated including the mean number of intersections per grid cell. Moreover, the number of intersections per unit of area can be equated to land use characterizations – high density urban cores, medium density urban areas, low density suburban areas and very low density rural areas. The distribution of these categories – the relative frequencies in each city – are compared to determine if among the case study cities an individual city's should be considered as supportive or limiting in growing cycling interests. More specific descriptions of the intersection density calculations are presented in the following section.

3.3.1.1 Data Collection

The analysis of intersection density in each city involves the collection of roadway and city boundary shapefiles from government open data sources and analyzing the spatial data using several tools in ArcGIS. The data used to represent the road networks and the municipal boundaries were collected from the case study cities' local government open data sources, using the most recent version, to ensure accuracy. The roadway data contain spatial representations of intersection locations. The city boundary shapefiles are necessary to limit the work to the existing boundaries. The specific data files and their source of retrieval are listed in the Table 2 below.

Table 2 - List of data sources used for the Intersection Density Analysis

City	Name of File (Year Pub.)	Source
Vancouver, BC	Intercensal Road Network Files (2020)	Statistics Canada
	Census Boundary Files (2016)	Statistics Canada
Portland, OR	Streets (2021)	PortlandMaps
	City Boundaries (2020)	PortlandMaps
	Willamette/Columbia River Ordinary High Water (2019)	PortlandMaps
Waterloo, ON	Intercensal Road Network Files (2020)	Statistics Canada
	Census Boundary Files (2016)	Statistics Canada
	Rivers (2019)	Region of Waterloo Open Data
Madison, WI	Street Centreline and Pavement Data (2021)	City of Madison Open Data
	City Limit (2017)	City of Madison Open Data

However, additional modifications to the source data are necessary to calculate intersection densities. The municipal boundaries of Portland and Waterloo have water features embedded within them. When the analysis grids are overlaid onto these cities, the areas containing these water features will, of course, have fewer intersections. As such, the presence of large water bodies will affect the accuracy of the results. To address this potential of error, it was necessary to retrieve and exclude the spatial data for the water features within these cities. For the City of Portland, the Willamette/Columbia River Ordinary High Water data file, retrieved from Portland's open data website, PortlandMaps, was used to represent the water features within Portland's municipal boundary. The Grand River, which runs through the Region of Waterloo, was represented by the Rivers data file, retrieved from the Region of Waterloo open data website. The areas contained within these shape files were excluded from the intersection density analysis using the "Erase" tool in ArcGIS which specifies areas to eliminate from future analyses.

Once the road network, municipal boundary, and water feature data files were collected, they were input into the ArcGIS program for further processing. Before beginning work with the data, a common projection – NAD 1983 – was established. More specifically Zone 10N was used for Vancouver and Portland, Zone 16N for Madison, and Zone 17N for Waterloo, to ensure accuracy.

3.3.1.2 Data Extraction

The process of calculating the density of intersections required a method of calculating the number of intersections over a defined area. The approach taken in this research was to create a new point dataset by using the intersect tool in ArcGIS. By completing this step, the program outputs a point where the roads intersect with each other and defines the location where the intersection occurred. The total number of newly created points then informs the number of intersections located within the case study cities.

With the locations of the road intersections defined, there was a need to create smaller spatial areas over which intersection densities could be calculated. To differentiate between the areas of high and low intersection density within the case study cities, it is necessary to divide the area within the municipal boundary into a grid of equal areas to ensure consistency. Because municipal boundaries often produce irregular shaped areas, this research aims to resolve the problem by using equal sized hexagons to better fit geographic boundaries. The hexagon tiles were created with the size of 1km^2 using the Generate Tessellation tool in ArcGIS with the extent set to the municipal boundary of the case study cities. Because the hexagon tiles created may cover areas outside of municipal boundary, it was then necessary to use the "Clip" tool in ArcGIS on the files containing the hexagon tiles to remove the areas outside of the municipal boundary.

With the hexagon tiles created and the locations of intersections determined, the calculation of intersection density happens by joining both sets of data spatially using functions in ArcGIS. The approach taken was to use the Spatial Join tool in ArcGIS to summarize the number of intersection points located within each hexagon tile. The value gathered from the Spatial Join function could be used to determine which tiles in which parts of the city contains a higher of lower density of intersections, thereby informing the areas that are more conducive to cycling.

Figure 2 - Hexagon tiles creating 1km^2 subdivisions of Vancouver, BC

However, as demonstrated in Figure 2 many hexagon tiles on the city edges are not at exactly 1km^2 in size. It is therefore necessary calculate densities for those zones based on the actual areas of the hexagon tiles. To do so, a field was created that contained the actual areas of all the hexagons; for most the value was 1km^2. But, for those along the municipal boundary, the areas were generated by ArcGIS and the fields were populated. Finally, actual intersection densities were calculated for all hexagon tiles in each city. The results computed form the basis of the comparison of built environment attributes of the candidate cities.

3.3.1.3 Data Classification

The previous step in the analysis produced a set of 1km^2 hexagons in each city; for each of those hexagons, the number of intersections per square kilometer is calculated. The next step in the analysis is to calculate the frequency of observations belonging to various categories. The classification of intersection density in the list below (Table 3) was determined based on known areas of high and low development density within the cities. Creating distributions (observations of the frequencies) for the presence of these categories in each of the case cities, allows for a comparison of the prevalence of cycling-conducive densities. Because essential destinations tend to be located close to places of residence in a high-density built environment, and requires short travel time and distance, it is assumed that cycling is preferable in a higher density area. The metrics for the comparison between the case study cities' built environment attributes will be determined by the dataset's statistical distribution.

Table 3 - Classification of Intersection Density

# of Intersections Points per unit of area	Description
0 – 100	Rural
100 – 200	Suburban
200 – 300	Medium Density
>300	High Density

3.3.2 Topography Account

The purpose of the topography analysis is to determine areas of the case cities where grades exist that may present challenges that dissuade cycling. With the assumption that fewer of these challenging topographic features means that the city on the whole is more conducive to cycling, this research aims to quantify the relative prevalence of these grades in the case studies.

To estimate the topography metric, the percent grade change in elevation was measured across both 1 and 10 metre squares overlaid on the case study cities. The motivation for this approach, including the two scales of assessment, is to find the relative frequency of zones that across their boundaries have grades that are potentially problematic for cyclists. One meter square assessments reflect a very disaggregate approach that best represents the actual topography; however, this scale may result in a resolution that is inconsistent with what a cyclist might experience. The 10 meter squares allow for a similar level of disaggregation, but may better capture a cyclist's perception as they traverse the areas measured. A second approach was to measure the percent grade of each segment of bicycle facility, with the segment lengths being defined by the GIS elements that represent the links. This third approach represents the least spatially disaggregate and may be most effective in capturing prolonged exposures to grades. This final method also allows for grades to be calculated across different cycling facilities. The quantitative variables calculated will be compared between each city to determine whether their topography will promote or dissuade cycling use.

3.3.2.1 Data Collection

The analysis of overall slope of the case study cities and slope of each segment of cycling facilities requires the data typically contained in digital elevation models (DEM). The DEM includes the height of each equal sized cells, either 1 or 10 metre squared, laid across an entire geographic area. The sources of the DEM collected for each city is listed in Table 4 below.

Table 4 - Digital Elevation Model Data Sources

City	Name of File	Source (Website)
Vancouver, BC	DEM (2013)	City of Vancouver Open Data
Portland, OR	USGS DEM Oregon 10 Meter (2021)	State of Oregon Geospatial Enterprise Office
Waterloo, ON	Southwestern Ontario Orthophotography Project (SWOOP) (2015)	University of Waterloo Spatial Data Library
Madison, WI	Digital Elevation Model (DEM) – 10 Meter (2019)	Wisconsin Department of Natural Resources

3.3.2.2 Data Processing

The following diagram, Figure 3, summarizes the specific steps taken to analyze the patterns of elevation changes across the entire area of each city. This process uses multiple spatial analysis tools in ArcGIS to generate the results. Because the DEMs collected from sources listed in Table 4 may contain information of a geographic area that extends far beyond the municipal boundaries, the "Extract by Mask" tool in ArcGIS is used to truncate the features of interest at the municipal boundary, and to eliminate the attributes (elevation) at that spatial location. Following this action, I used the resulting DEM as the basis of the calculation of the steepness of slope within each cell across the entirety of each case study city's area in ArcGIS's slope tool. The resulting file, containing the slope information, was reclassified into the range of slopes listed in Table 5, which has been established based on the known ranges of previously discovered in Chapter 2.

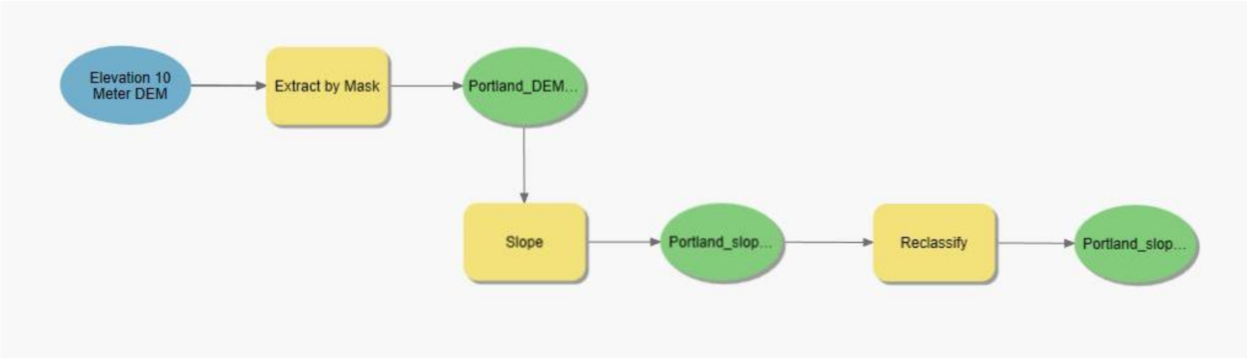


Figure 3 - The process of creating an elevation model that has a limited geographic scope and categorized in a range of known value

The Figure 4 outlines the process of determining the elevation changes along segments of bicycle facilities using the Add Surface Information tool in ArcGIS. The tool combines the information of two key variables, bike lane segments and elevation, to quantify the grade and, as a result, help to understand how the topography could impact the comfort of cyclists who are using the facilities. The location bike routes were represented by the bikeway shapefiles collected from each case study city, and the topographic changes of the cities were represented by the DEM. The tool could also calculate the maximum, minimum, and average, slope of each segment of cycling facility to support a better understanding of implications on the cyclists' comfort. This analysis uses the average slopes of each cycling facility segment for a balanced consideration of data. The resulting data are reclassified into the known categories listed in Table 5. The results revealed in this process will allow for a comparison between the level of comfort of using the cycling facilities within each city.

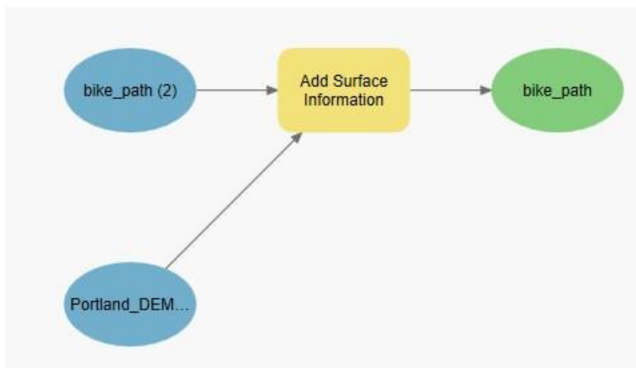


Figure 4 - The process of adding elevation information into an existing shapefile

3.3.2.3 Data Classification

The data gathered through the methods described above are compared to a set of known values determined by (Matias et al., 2020), as listed in Table 5. The categories denote the level of comfort at each range of slope. The data derived from the DEM for each case study city are compiled into frequency distributions, with the proportions of total zones belonging to each category of slope. These distributions are compared across the cities to determine whether the topographic attributes of the case study cities have reduced the suitability of cycling within them.

Table 5 - A table outlining the relationship between a range of slope and the comfort of cyclists (Matias et al., 2020)

Gradient	Description	Suitability
0-3%	Level	Good for cycling
3-5%	Gentle Slope	Suitable for cycling up to medium distances
5-8%	Moderate Slope	Inappropriate for long and medium distances
8-10%	Steep Slope	Acceptable for very short distance

3.3.3 Bicycle Network Connectivity and Density Account

The quantitative analysis used for the bicycle network account includes two metrics – an estimate of the bicycle network connectivity, as well as bicycle network length within a kilometre square. The purpose of this analysis includes an examination of connectivity of each cities' bicycle network and a comparison between the density and connectivity of bicycle facilities in high- and low-density areas of each city.

Determining the connectivity of cycling facilities is important because the inability of cyclists to reach their destinations on dedicated safe cycling routes will deter cyclists from cycling. Moreover, previous research has demonstrated that many roadways in North American cities were not built to protect cyclists, resulting in large and impactful gaps in the overall connectedness of the bicycle infrastructure. The density of cycling facilities is also important to be considered because a high density of cycling facilities reduces the time cyclists are required to travel in unsafe spaces and thereby influencing their desirability to cycle. Therefore, the results of this analysis provide evidence as to whether the existing bicycle network in each city has been conducive or unfavourable for promoting cycling as a viable travel option.

3.3.3.1 Data Collection

The analysis of bicycle network connectivity and density uses the following data collected from publicly available sources.

Table 6 - List of shapefiles used for bicycle network analysis

City	Name of File	Source (Website)
Vancouver, BC	Bikeways (2021)	City of Vancouver Open Data
	Boundary Files (2016)	Statistics Canada
Portland, OR	Bicycle Network (2020)	PortlandMaps
	City Boundaries (2021)	PortlandMaps
Waterloo, ON	Active Transportation (2021)	City of Kitchener
	Bikeway Network (2020)	The City of Cambridge
	Major Active Transportation Routes (2018)	City of Waterloo
	Trails and Pathways (2021)	City of Waterloo
	Cycling (2020)	Region of Waterloo
	Boundary Files (2016)	Statistics Canada
Madison, WI	Bike LTS (2021)	City of Madison
	Bike Paths (2021)	City of Madison
	City Limit (2017)	City of Madison

3.3.3.2 Data Processing

3.3.3.2.1 Bicycle Network Connectivity

The analysis of cycling network connectivity involves multiple processes in ArcGIS and Microsoft Excel as shown in the following figure. The process begins with importing the relevant shapefiles, such as the bicycle facilities and the city boundary files, into a single file geodatabase (Figure 5). The spatial representation of bicycle facilities forms the network dataset for each city and the city boundaries form the basis of laying out 1km^2 hexagon zones across the case study cities to generate a set of origin and destination points (Figure 6). Because the line segments of cycling facility in the data file may contain inaccuracies when intersections are physically near each other but are not registered as connected, an important step must be taken to resolve the problem is by using the “integrate” tool in ArcGIS to make all line segments connect with each other when they physically intersect.

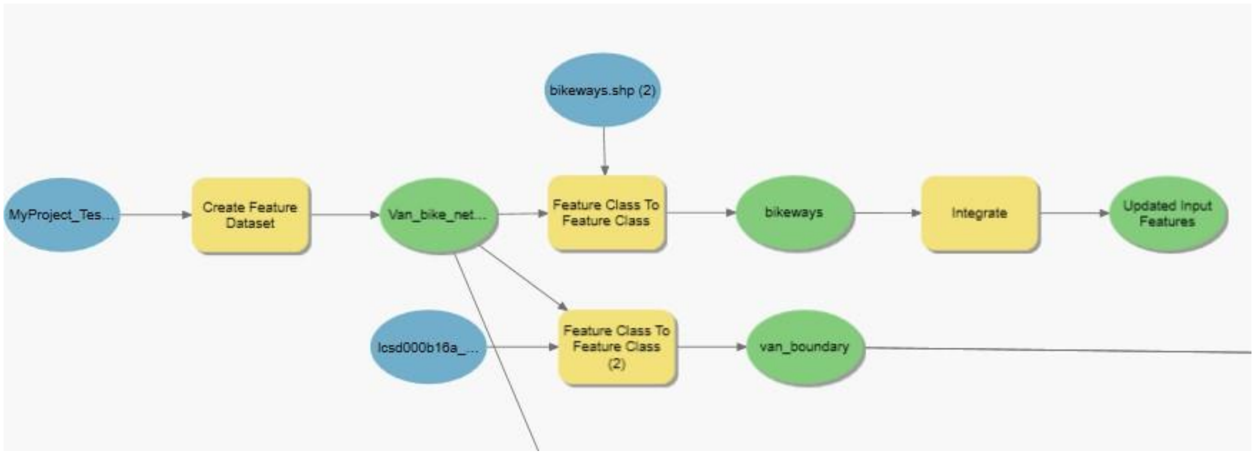


Figure 5 - The process of importing shapefiles into the file geodatabase

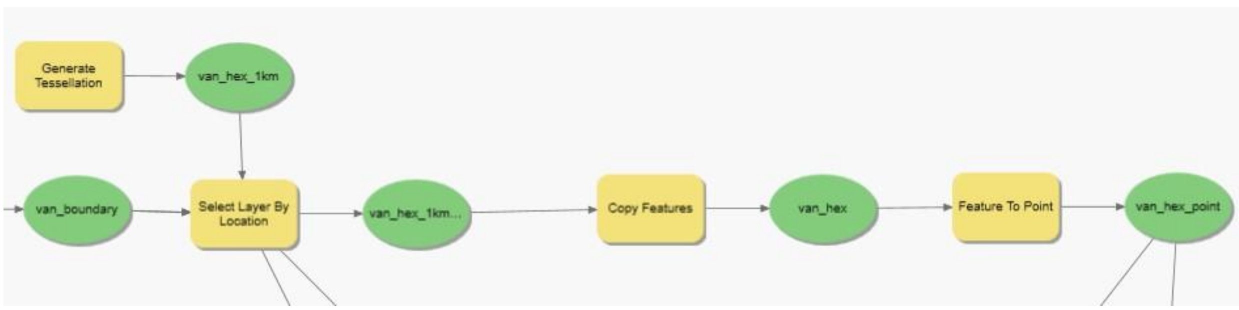


Figure 6 - The process creating 1km^2 hexagon zones and origin and destination points they represent

The network dataset built for this analysis can then use the revised and integrated bicycle network file to construct all bicycle facility paths (connections of individual segments) in the city. The results generated from this analysis will reveal the percentage of destination zones a cyclist can access from the origin using only the dedicated bicycle facilities.

The next step of the analysis process requires different set of functions to summarize the record of line connections. The following diagram outlines the flow beginning from gathering the lines file containing information from all connections. Since it is possible for origin and destination to be the same, the select by attributes tool was used to remove these instances to make the data more accurate. The next process outputs a table that contains the count of instances where line connections begin with a specific, unique origin point. The resulting summary then will be able inform how many other points can be reached from a particular zone within the case study cities. The value gathered can also be combined with the existing shapefile of hexagon zones to visualize the range of connections available within a city.

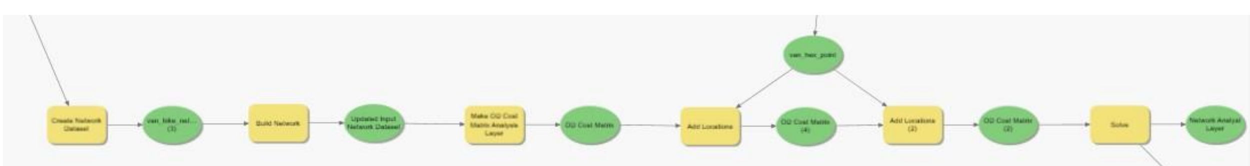


Figure 7 - The process of creating and OD Cost Matrix solver

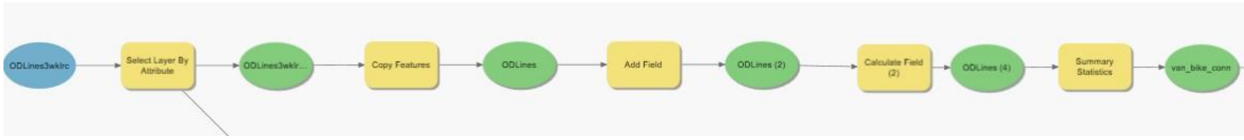


Figure 8 - The process of summarizing the origin and destination pairs

The last process of this analysis is the combining of the existing shapefile of 1km^2 hexagon zones and the table containing information of how well connected they are with each other by bike. However, because the hexagon layout contains areas outside of the city boundary, it is necessary to use the "clip" function to limit the data to the scope of this study. The detailed process of combining and formatting the data involves the steps outlined in the following Figure 9. The result of this process is a visual representation for each hexagon of its relative strength of connectivity.

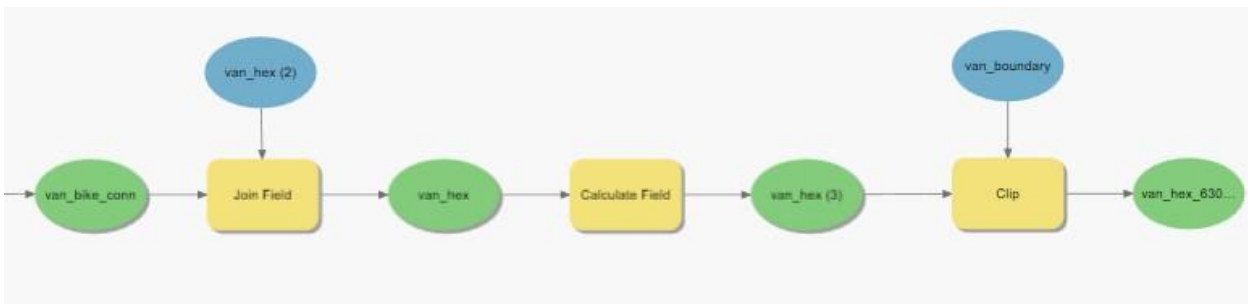


Figure 9 - The process of combining the summarized data with the hexagon shapefile

3.3.3.2.2 Bicycle Network Density

The steps to quantify the density of bicycle facilities within the case study cities utilizes the hexagon zones that were outlined previously. This process summarizes the total length of bicycle facilities contained within each hexagon, representing a 1km^2 area within a city. This density metric is a simplified approach to estimate the range of likeliness of the cyclists' origin and destination being close to a dedicated cycling route.

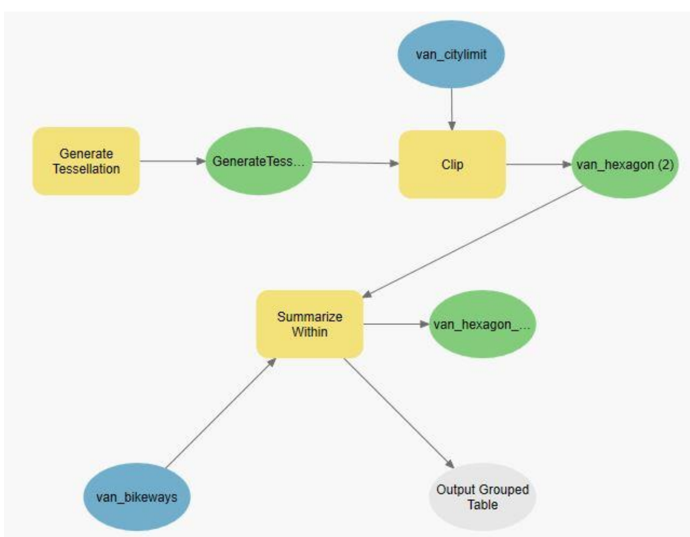


Figure 10 - The process of calculating the length of cycling facilities within a square kilometre

3.3.3.3 Data Classification

The results from the analysis of each case study cities will be compared with each other to determine if cities have been successful to create a unified network to maximize cycling comfort. The evaluation will be informed by the percentage of other destinations reachable by using only the cycling infrastructure. If the location could access a high proportion of destinations across the city, it represents that cyclist could use safe cycling infrastructure to travel to a high number of places. However, if the location is connected to only a few destinations, or not connected to the cycling network at all, it represents that there are little to no options to travel around the city by bike.

3.3.4 Climate Account

With cycling being a mode of transport with substantive exposure to weather, it is important to consider the climate to determine if cities are naturally more suitable for cycling. Cities with warm weather, and low to no precipitation, tend to be more conducive for cycling; in contrast, cycling is less likely to occur in cities with extreme temperatures and high precipitation rates. As such, the analysis of temperature and precipitation data can inform whether the case study cities experience weather conditions that encourage cycling ultimately resulting in a potential mode shift. The quantitative variables used for the climate account include data representing historic temperature and precipitation observations for each case study city.

3.3.4.1 Data Collection

The data for the climate account were collected from the following publicly sources; these government agencies are relied upon in the study because they offer the most complete and credible information.

Table 7 - List of data sources for gathering weather data

City	Name of File	Source (Website)
Vancouver, BC	Canadian Climate Normals (1981-2010)	Environment and Climate Change Canada
Portland, OR	National Oceanic and Atmospheric Administration (NOAA) Online Weather Data – Portland, OR Weather Forecast Office	National Oceanic and Atmospheric Administration (NOAA) National Weather Service
Waterloo, ON	Canadian Climate Normals (1981-2010)	Environment and Climate Change Canada
Madison, WI	National Oceanic and Atmospheric Administration (NOAA) Online Weather Data – Milwaukee/Sullivan, WI Weather Forecast Office	National Oceanic and Atmospheric Administration (NOAA) National Weather Service

3.3.4.2 Data Processing

The temperature and precipitation data gathered were input into Microsoft Excel to create charts that allow for the visualization and comparison of the weather patterns of each case study city. The following diagram outlines the process of analysis.

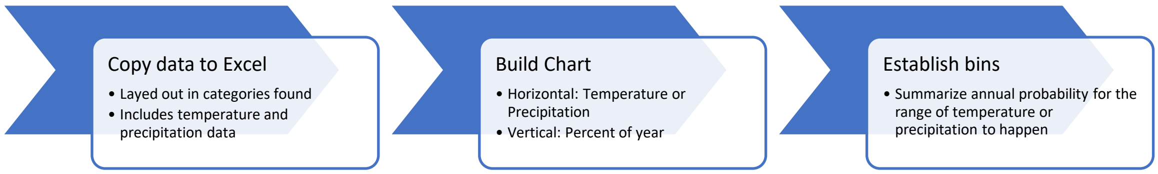


Figure 11 - The process of creating a chart for the weather data

3.3.4.3 Data Classification

The following metrics were chosen to determine the suitability of cycling within the case study cities:

- The proportion of annual days with temperatures that fall within the ideal cycling temperature range, identified by Böcker and Thorsson (2014) as between 5 to 25 degrees Celsius.
- Days in a year without precipitation with fewer days of measurable precipitation being considered a positive attribute, and annual days without snowfall.

3.3.5 Demographics Account

Previous research has indicated that cycling tends to be more popular among the youth and post-secondary student population, as compared with other age groups (Winters et al., 2010). Based on this observation, this research seeks to quantify the total population in each city belonging to these demographic cohorts (Chaney et al., 2014). Based on available data, the quantitative variable used for the demographics account are the number of individuals enrolled in post-secondary institutions in each case study city and the amount of people belonging to the 15 to 34 age group. Through gathering the value of each population group, the research will then be able to compare the cities' demographics and their potential in promoting cycling.

3.3.5.1 Data Collection

The gathering of demographic data for the case study cities involves retrieving data from the sources listed in the following table, Table 8. The data collected through these sources are consistent with the most recent general census or population surveys in Canada and the United States.

Table 8 - List of sources for gathering the demographic information

Case Study City	Data Type	Source	File Name
Vancouver, BC	Youth Population	Canadian Census 2016	Census Profile, 2016 Census – Vancouver, City [Census subdivision]
	Post-Sec. Enrolment	British Columbia Data Catalogue	Full-time Equivalent Enrolments at B.C. Public Post-Secondary Institutions
Portland, OR	Youth Population	United States Census Bureau	American Community Survey Estimates 2019
	Post-Sec. Enrolment	United States Census Bureau	American Community Survey Estimates 2019

Waterloo, ON	Youth Population	Canadian Census 2016	Census Profile, 2016 Census – Kitchener – Cambridge – Waterloo [Census metropolitan area]
	Post-Sec. Enrolment	Region of Waterloo	Year-End 2016 Population and Household Estimates for Waterloo Region
Madison, WI	Youth Population	United States Census Bureau	American Community Survey Estimates 2019
	Post-Sec. Enrolment	United States Census Bureau	American Community Survey Estimates 2019

3.3.5.2 Data Processing

The demographic data are analyzed using Microsoft Excel and visualized using charts and graphs once the data have been gathered. The chart building process takes simple tasks to layout the data in an informative approach. For this analysis, a table is used to conveniently compare between the demographic data of cities. The rows of the table include the two main data that this analysis compares, the youth population and post-secondary enrolment. The columns of the table will be the case study cities and listing below them the data relating to them. Besides the actual values, the table will also list the amount to the proportion of the entire population of the case study cities.

3.3.5.3 Data Classification

The proportion of population between the ages of 15-35, and the proportion of population enrolled in a post-secondary institution, serves as comparators of the demographic analysis. As the youth population (15-35 years old) within a city is the population group that contains the highest proportion of cyclists (Winters et al., 2010), the evaluation process could use this variable as an indicator of a city's potentiality to popularize cycling. Therefore, the evaluation process would involve comparing the proportion of youth population and the proportion of population enrolled in a post-secondary institution, in the two similar sized cities (e.g., Vancouver and Portland), to determine which city has a population that is more likely to cycle than the other.

3.4 Qualitative Analysis

3.4.1 Policy Account

Recall that the hypotheses being tested in this thesis include the idea that physical attributes will either position a city well for cycling or create impediments to significant cycling mode shares for commuting purposes. The thesis work is also motivated by the observation that some cities exceed the performance expected based only on the physical attributes, while other cities lag relative to the expected performance. One explanation for these unexpected performances is that the planning profession has been effective (or ineffective) through policy, education and infrastructure, in influencing traveler behavior with regard to cycling.

To evaluate the possible impacts that planning has had on observed cycling mode share for commuting purposes, the approach taken is to review previous and current transportation planning documents that contain elements related to cycling (and active transportation more generally). In reading these plans, attention is paid to the extent to which the documents contained purposeful and meaningful approaches to build upon a city's positive physical attributes and address the negative physical attributes.

The qualitative variables used for the policy analysis account include the effectiveness of the bicycle plans and policies published for each case study city. The active transportation plans and policies often outline the long-term vision for future development of the active transportation services in cities. The plans and policies also function to set a direction of how new infrastructure is to be developed and describing metrics for success. As infrastructure development and mode shift programming are dependent on local decisions and policy guidance, the evaluation of policies is necessary to understand each city's activities to realize increased cycling. Therefore, evaluating the robustness of the policies in influencing more people to use cycling is an effective method to understand the determination of the local governments to shift travel modes.

3.4.1.1 Policy Document Selection

The selection process of the planning policies to be included in this research is based on the relevancy to the research topic. Since the research aims to determine policy responses to challenges to cycling in the case study cities, the selection of review documents prioritizes cycling or active transportation plans published by each city. If a plan specifically addressing cycling or active transportation use is not present, or a subsequent cycling plan is unavailable, the plans that address all transportation matters in the city are considered. Also, because the process of building a new transportation habits often takes prolonged periods of time, this research reviews the three most recent versions of cycling plans published over the course of the past 20 years.

The gathering of the planning documents involves visiting the websites of the related government organizations, examining the relationship between the current and previous documents, and locating the documents for downloading. The following table, Table 9, lists the transportation planning policy documents that are in the scope of this research.

Table 9 - List of planning documents reviewed

Case Study City	Name of Document (Year Pub.)	Source
Vancouver, BC	Comprehensive Bicycle Plan (1988)	City of Vancouver
	Vancouver Bicycle Plan: Reviewing the Past, Planning the Future (1999)	City of Vancouver
	Transportation 2040 (2012)	City of Vancouver
Portland, OR	Bicycle Master Plan (1996)	City of Portland
	Portland Bicycle Plan for 2030 (2010)	City of Portland
	Portland 2035 Transportation System Plan (2020)	City of Portland
Waterloo, ON	Region of Waterloo Cycling Master Plan (2004)	Region of Waterloo
	Region of Waterloo Active Transportation Master Plan (2014)	Region of Waterloo
	City of Kitchener Cycling and Trails Master Plan (2020)	City of Kitchener
	City of Cambridge Cycling Master Plan (2020)	City of Cambridge
	City of Waterloo Transportation Master Plan (2020)	City of Waterloo
Madison, WI	Bicycle Transportation Plan for the Madison Metropolitan Area and Dane County (2000)	City of Madison
	Bicycle Transportation Plan for the Madison Metropolitan Area and Dane County (2015)	City of Madison

3.4.1.2 Process of Determining Key Policy Interventions to Overcome Barriers to Cycling

The process of understanding the cities' attempts to promote cycling towards improved mode share involves a city-by-city, chronological review of active transportation plans and policies. The city-by-city evaluation involves categorizing the candidate cities by their size and geography and evaluating the robustness of their published plans to address their physical challenges. For that reason, the most recent plan for Vancouver will be compared with Portland's, while Waterloo's planning response will be compared with those from Madison Wisconsin's. These pairings are motivated by the similarities in the cities' sizes and densities.

The policies were also analyzed chronologically by their publication year to understand the changes suggested from each policy update and to examine the progress towards implementation of goals. The process to complete a chronological analysis of policies involves the comparison between the current and previous version of active transportation policies for each city. With the update interval of each city's policies being around ten years, a duration that allows for evidence to be gathered on how these plans have influenced mode shifts to cycling, evaluating the policies chronologically allows for the determination of how the needs have changed, if the previous plan was successful in stimulating cycling rates, and implementation progress. The review process will then involve listing the implementation strategies of each of the case study cities to determine if the cities have specifically addressed the natural challenges to make cycling popular.

3.4.1.3 Evaluation Metrics

The process of establishing a set of metrics for comparison between the policies and plans of each case study city involves identifying the evidence that cities have taken steps to overcome their inherent barriers to popularizing cycling. The steps taken in this research will be to re-visit the known issues revealed by the quantitative analysis and determine if the cities have actively addressed these obstacles based on the frequency and depth of implementation strategies evident in their plans. Then, the observed strategies are compared with known worldwide best practices to determine whether the plans published by the case study cities are appropriate and likely to overcome the local challenges. The ultimate metric of success is the observed share of people cycling in the case study cities.

3.5 Summary

This chapter discussed the process of gathering and analyzing data in support of determining those attributes that promote and deter cycling in Vancouver, Portland, Waterloo, and Madison. An in-depth review of each case study city's key geographic features including the urban density, elevation changes, bicycle network connectivity, climate, is necessary to accurately evaluate the overall suitability of cycling in each city. These physical attributes are complemented by an assessment of the demography in the cities, more specifically the prevalence of age groups known to have greater propensity to cycle.

The likelihood of achieving successful outcomes, particularly understanding their strengths and challenges, depends directly on how cities address shortcomings and create opportunities; the cities' approaches ought to be evident in their planning documents. With the goal of this thesis being to examine the suitability of cycling of cities in the North America, this chapter has presented a strategy of reviewing planning documents to assess their treatment of the issues that were identified in the geographic and demographic evaluations.

Chapter 4: Quantitative Results and Discussions

4.1 Introduction

This chapter introduces the quantitative results of the evaluation of physical and demographic attributes of each case study city. The results of the quantitative evaluation inform whether these attributes are conducive (or dissuasive) to cycling in each case study city. The quantitative data analysis uses specific attributes (e.g., Built Environment, Topography, Bicycle Network Connectivity and Density, Climate, and Demographics) as metrics of suitability for cycling as described in the previous chapter.

The comparison of results from the quantitative analysis with the most recent observed cycling mode share for commuting activities will follow to determine if the cycling rate supports or refutes the assumptions made about a city's suitability for cycling. Although the commuting mode share variable does not represent all cycling activities that takes place in a city, this is the most accessible metric to represent the overall cycling activity. Moreover, one can expect that there is some correlation between the likelihood to cycle for commuting and overall cycling rates (i.e., including non-work utilitarian and recreational trips). However, when a discrepancy arises between the assessment of suitability and the observed cycling rates, each city's policy responses are evaluated in an effort to explain these differences. It is important to review both elements – the physical attributes that promote cities' suitability for cycling and the strength of the cities' policy responses – together to produce the most comprehensive view of a city's suitability for new and current cyclists.

4.2 Quantitative Analysis Results

4.2.1 Built Environment

Moudon et al. (2005) described the ideal built environment for cycling as areas with a high urban density. While many metrics for density have been proposed and applied (e.g., population density, employment density, Floor Area Ratio (FAR)), this research uses the density of road intersections instead, to determine areas with different levels of urban density. The quantitative metric used is the number of intersections per square kilometer observed within the city boundaries. Naturally, there is a distribution of observations within each city. To allow for an appropriate comparison, the results are shown here as the proportion of all analysis areas (1km^2 zones) that have densities belonging to a density category.

Because the existing literature does not establish a standardized scale denoting the relationship between the density of road intersection and urban density, this research uses known locations of high density built form in the case study cities to determine a logical range of intersections associated with each built form. The following Table 10 presents details of classification range used by this research.

Table 10 - Classification Ranges for Intersection Density Analysis

Intersections per Kilometre Square	Associated Built Form
0	Rural Areas
0 – 100	Low Density Suburban Areas
100 – 200	Mid Density Areas
200 – 300	High Density Areas
300 +	Very High Dense Areas

The analysis of road intersection density reveals that a small proportion of zones in Waterloo and Madison contain a high density of intersections (Figure 12). In fact, 62% of Waterloo zones and 56% of Madison zones belong to the lowest category of the scale, between 0 – 100 intersections per kilometre square. When compared to Portland and Vancouver, where only 35% and 8% of zones respectively are in the low density category, it becomes obvious that Waterloo and Madison have generally lower densities that reflect a challenge to achieving cycling goals. The predominant, low density areas, present several barriers for cyclists including the sparse distribution of essential destinations in a community and requiring cyclists to travel long distances to reach most of their desired destinations. Therefore, based on the results of the intersection analysis, the built environment in Waterloo and Madison does not make cycling activities as convenient as can be expected in Portland or Vancouver.

In contrast, Portland and Vancouver demonstrate that the built environments in both cities are conducive to cycling because they more of their spatial analysis areas have a high density of intersections. Figure 15 and Figure 16, demonstrate that both much of Vancouver and Portland are areas with medium to high urban density. Figure 12 also show that Portland and Vancouver have equal distribution of intersection density, but Vancouver's built environment is denser than Portland because Vancouver has fewer low density zones. However, with 56.7% and 44.4% of Vancouver and Portland respectively belonging in the high or very urban density category (Figure 12), as compared to 5.27% in Waterloo and 5.15%, both cities are considered highly favourable to cycling use. As places with a high urban density tend to have essential destinations within a short distance, cycling will then become a more convenient transport mode.

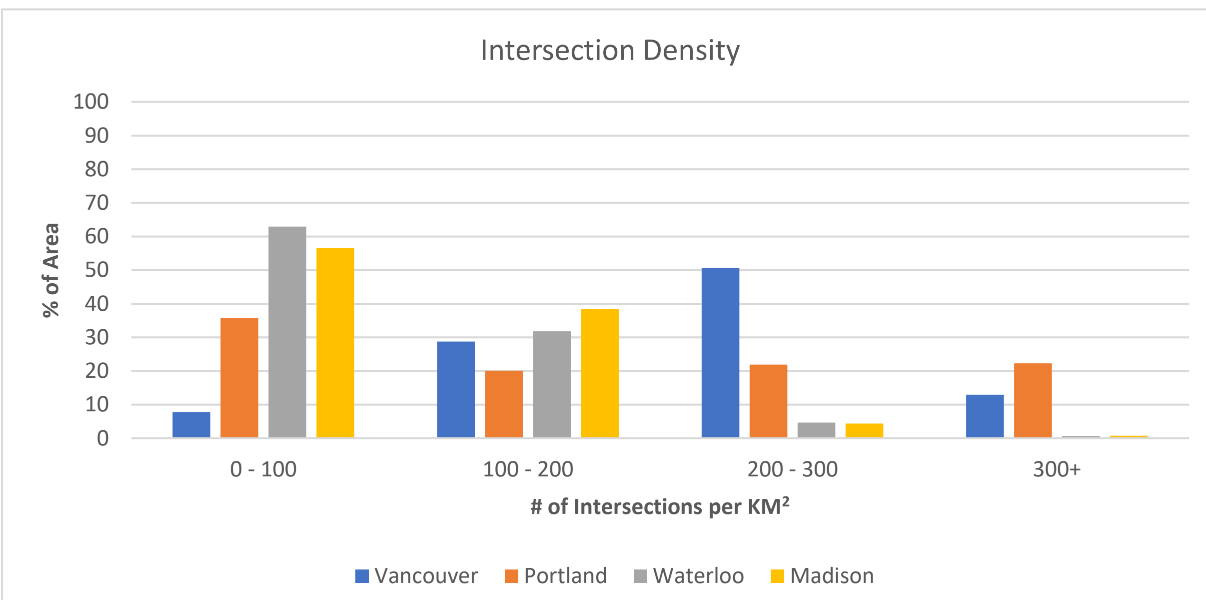


Figure 12 - Proportion of a city containing the value of intersection density

In summary, the built environment attribute, represented by the density of intersections, appears to be indicative of more favorable conditions for cycling in Portland and Vancouver than in Waterloo and Madison. In an effort to summarize the various comparisons that are made among the case cities, the results of the intersection density analysis and its interpretation with regard to promoting cycling, forms the basis of scoring the built environment attribute in this research. The following Table 11 describes the associated rankings for each case study cities.

Table 11 - Classification of the supportiveness to cycling revealed by case study cities' built environment attribute

Account	Vancouver, BC	Portland, OR	Waterloo, ON	Madison, WI
Built Environment	●	●	✕	✕

Legend:

Supportive for Cycling: ●

Supports Cycling Partially: ▲

Not Supportive for Cycling: ✕

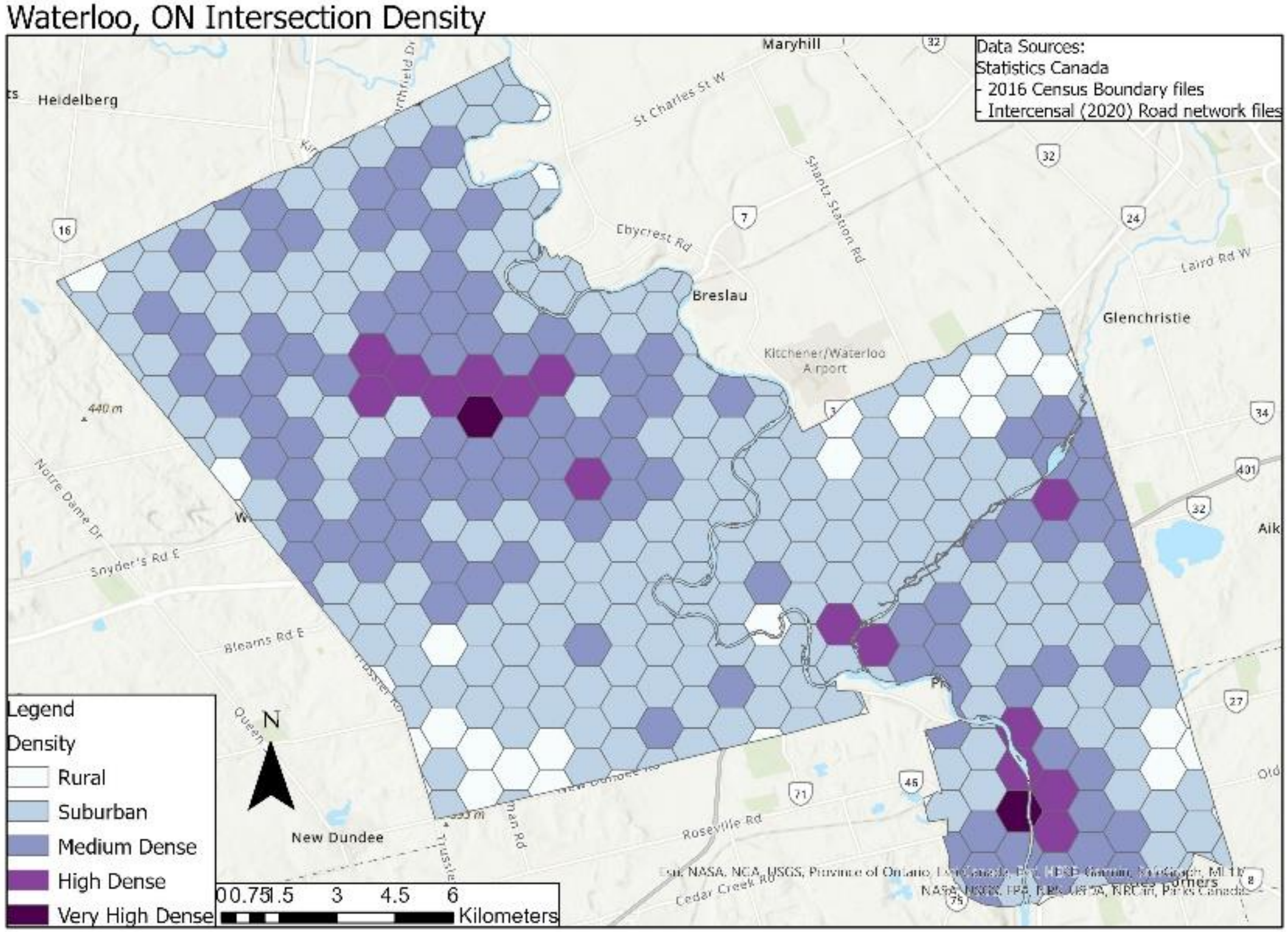


Figure 13 - Intersection Density of Waterloo

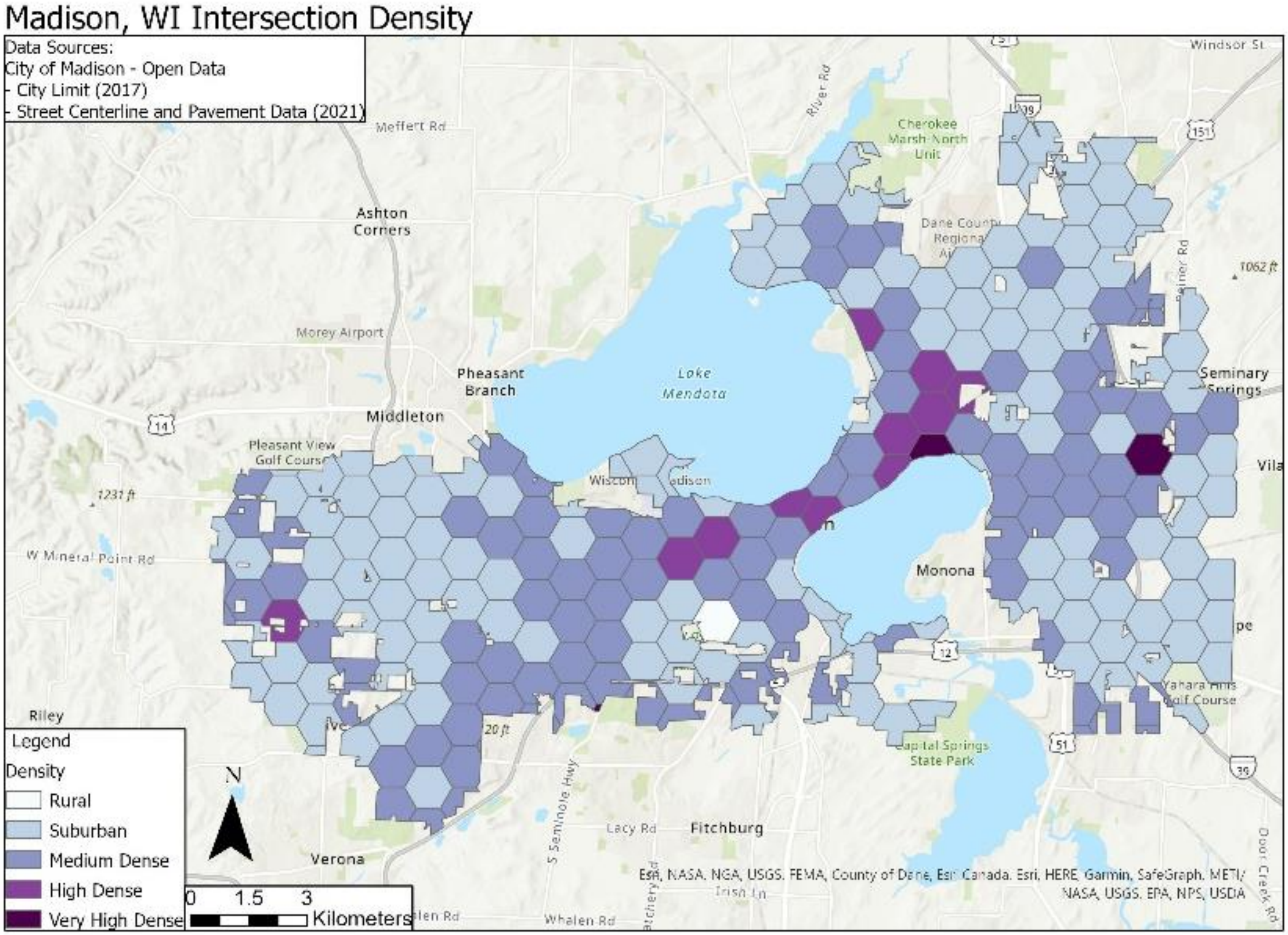


Figure 14 - Intersection Density of Madison

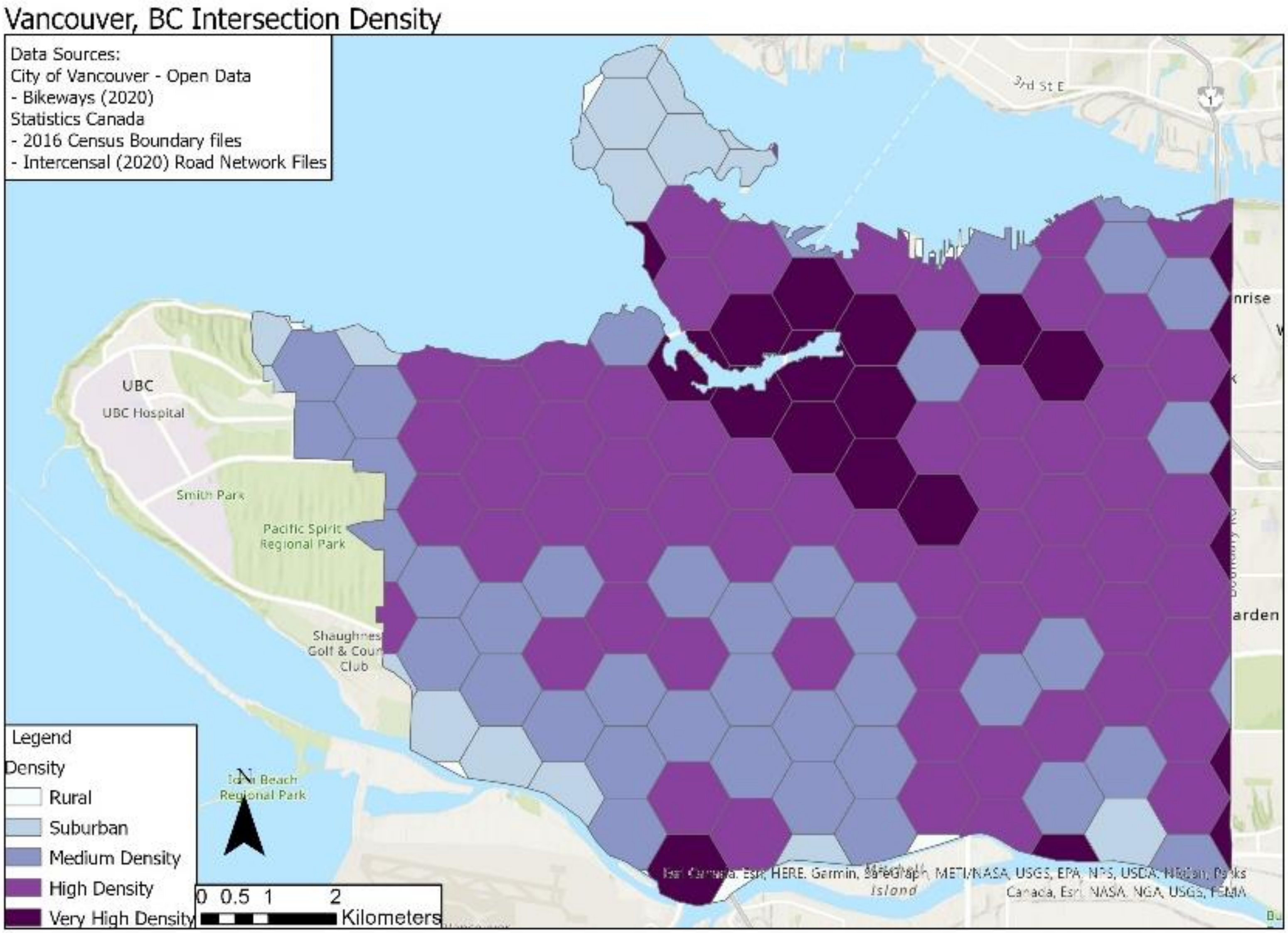


Figure 15 - Intersection density of Vancouver

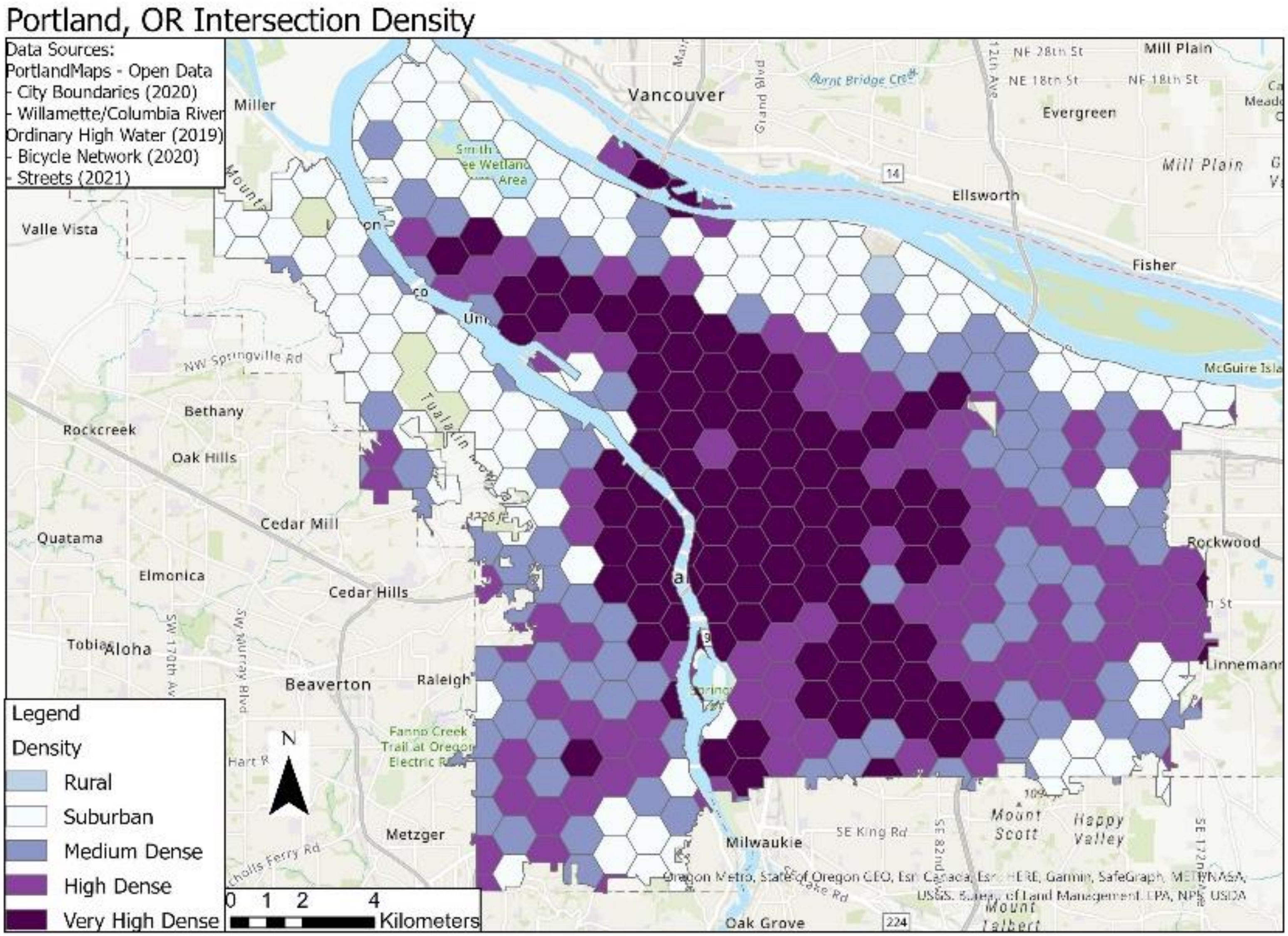


Figure 16 - Intersection density of Portland

4.2.2 Topography

The topographic changes along the route of cyclists can create barriers to cycling's attractiveness among transportation options because the presence of vertical changes requires significant physical exertion by the cyclists. To determine the extent of grade changes' potential impacts on the desirability of cycling, the topographic changes of each case study city were derived with an analysis of the slope of the subdivided areas using digital elevation models (DEM). The resulting data are classified using a scale suggested by Matias et al. (2020) listed in Table 12. The table of classification outlines the relationship between the gradient and the level of suitability for cycling necessary to determine if the topography of the case study cities is conducive to cycling.

Table 12 - The relationship between the gradient and suitability of cycling (Matias et al., 2020)

Gradient	Description	Suitability
0-3%	Level	Good for cycling
3-5%	Gentle Slope	Suitable for cycling up to medium distances
5-8%	Moderate Slope	Inappropriate for long and medium distances
8-10%	Steep Slope	Acceptable for very short distance

The elevation changes of cities are analyzed in two parts. The first part is the city-wide topography analysis where the slopes of subdivided areas across the entirety of the case study cities were calculated. The second is the analysis of elevation changes along cycling routes, which allows for an understanding of how the existing cycling facilities are impacted by topography.

4.2.2.1 City-wide Topography

The result of the city-wide topographical analysis demonstrates that the topography of Madison may constitute a barrier to cycling. With 54% of the area within Madison's city limit containing a gradient that produces physical challenges to cyclists (Figure 17), the results suggest that city-wide cycling may be challenging for most users. However, Figure 17 reveals that many of the steep areas are in fact in the suburban areas outside of the city centre, as identified in Figure 14. Given this observation, topography may become more problematic in Madison for those cyclists who wish to travel between the city centre and the suburban areas, because they will likely experience a steep slope on their journey. Therefore, the results indicate that the propensity to cycle in Madison is negatively impacted by the challenging slopes, particularly for those trips through suburban areas.

On the other hand, the analysis shows that the topographies of Vancouver and Waterloo are potentially less problematic for cycling when compared to Madison. About 35.7% of Vancouver and 26.8% of Waterloo experience grades that the literature suggests (Matias et al., 2020) are not suitable for cycling or are suitable for only a short distance; thus, flat and gentle slopes comprise about two-thirds of both cities, which makes cycling comfortable (Figure 18, Figure 19). The conclusion for Vancouver and Waterloo is that while the topographies of both cities produce some challenges to cyclist when travelling across the cities, these cities appear to have a natural advantage when compared to Madison.

Of the four case study cities, the topography of Portland has the highest proportion of flat areas that are suitable for cycling activities. Figure 20 demonstrates that 54% of Portland zones are in fact areas containing low to no slope that are ideal for cycling activities. This implies that many people residing in Portland can travel to another corner of their city without experience very challenging slopes, which could lead to a greater number of easily completed trips for cyclists.

When one correlates the areas within Portland to the intersection density analysis, as demonstrated in Figure 20, the areas with steep slopes are located away from the city centre and most inhabited areas (see Figure 16). The fact that the relatively small number of difficult elevation changes are located away from high density areas further suggests that the topography of Portland is conducive to cycling.

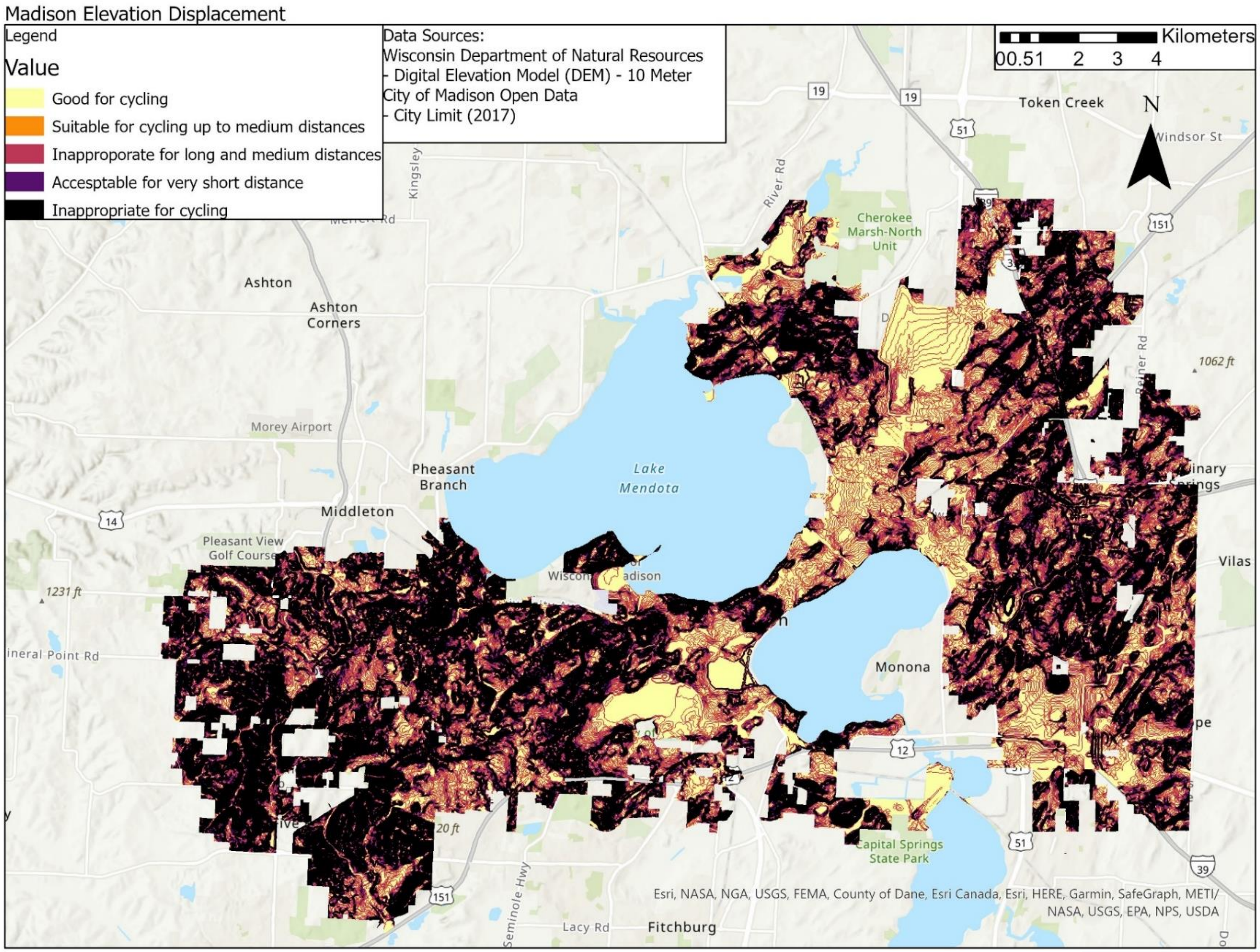


Figure 17 - Gradient of Madison

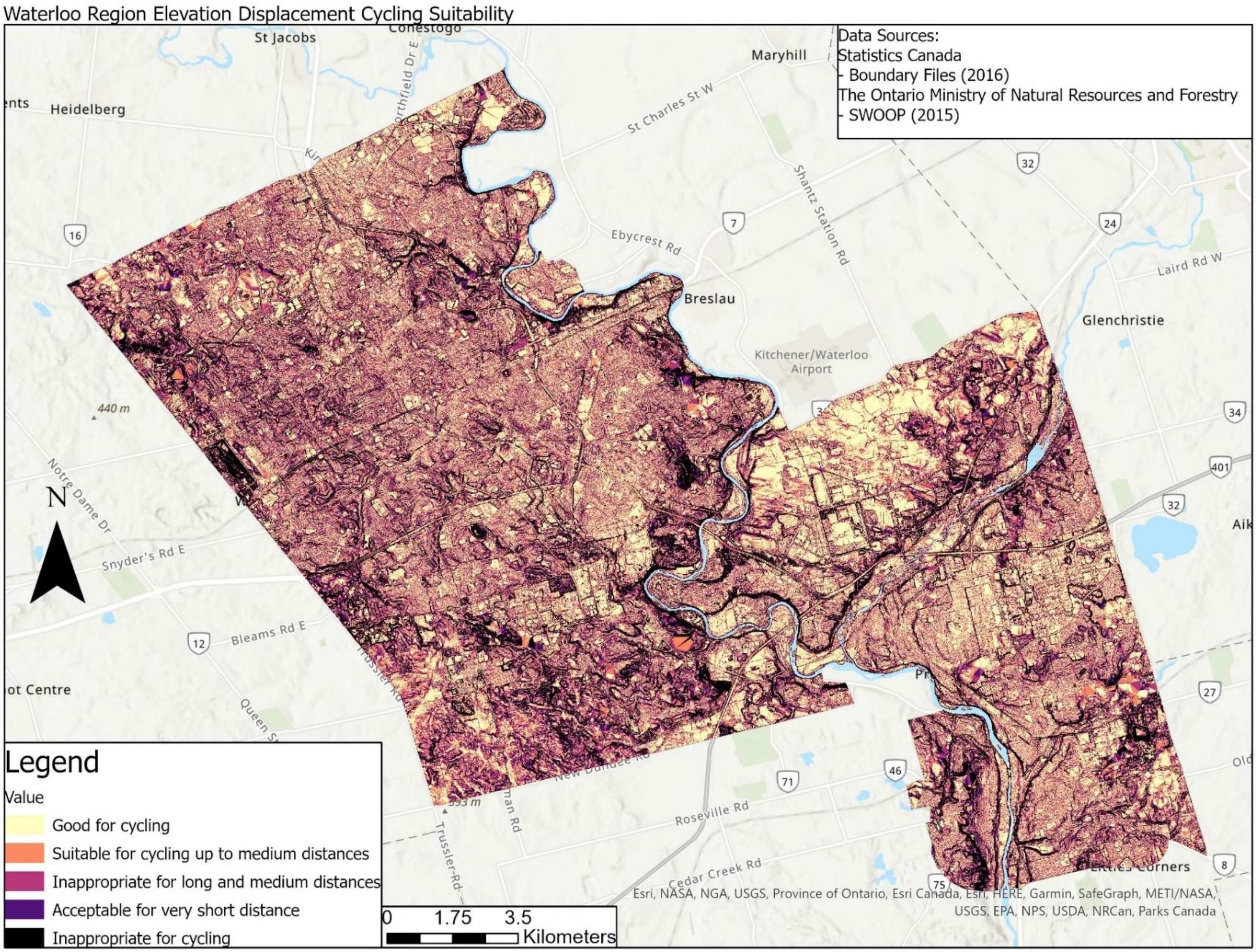


Figure 18 - Gradient of Waterloo

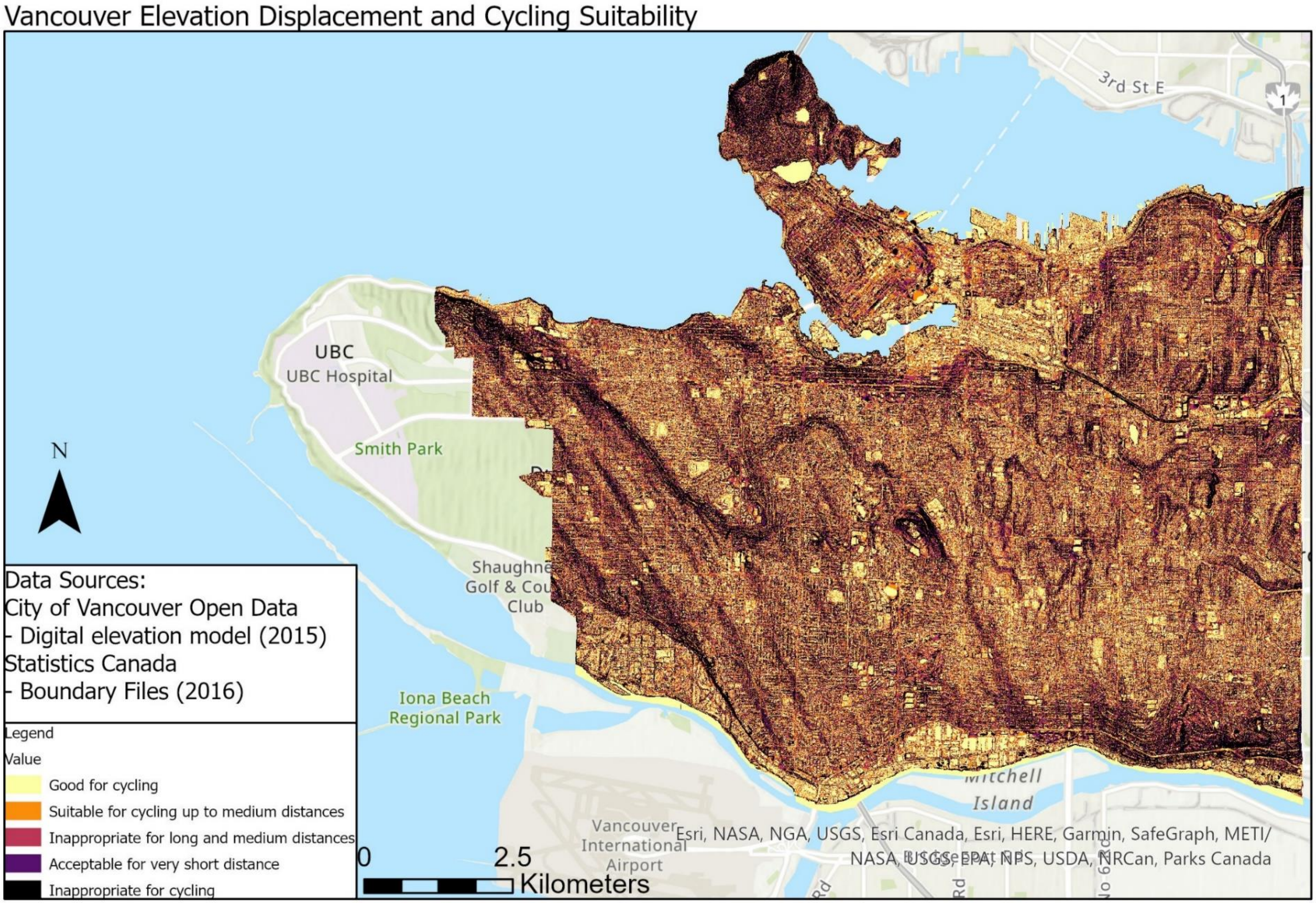


Figure 19 - Gradient of Vancouver

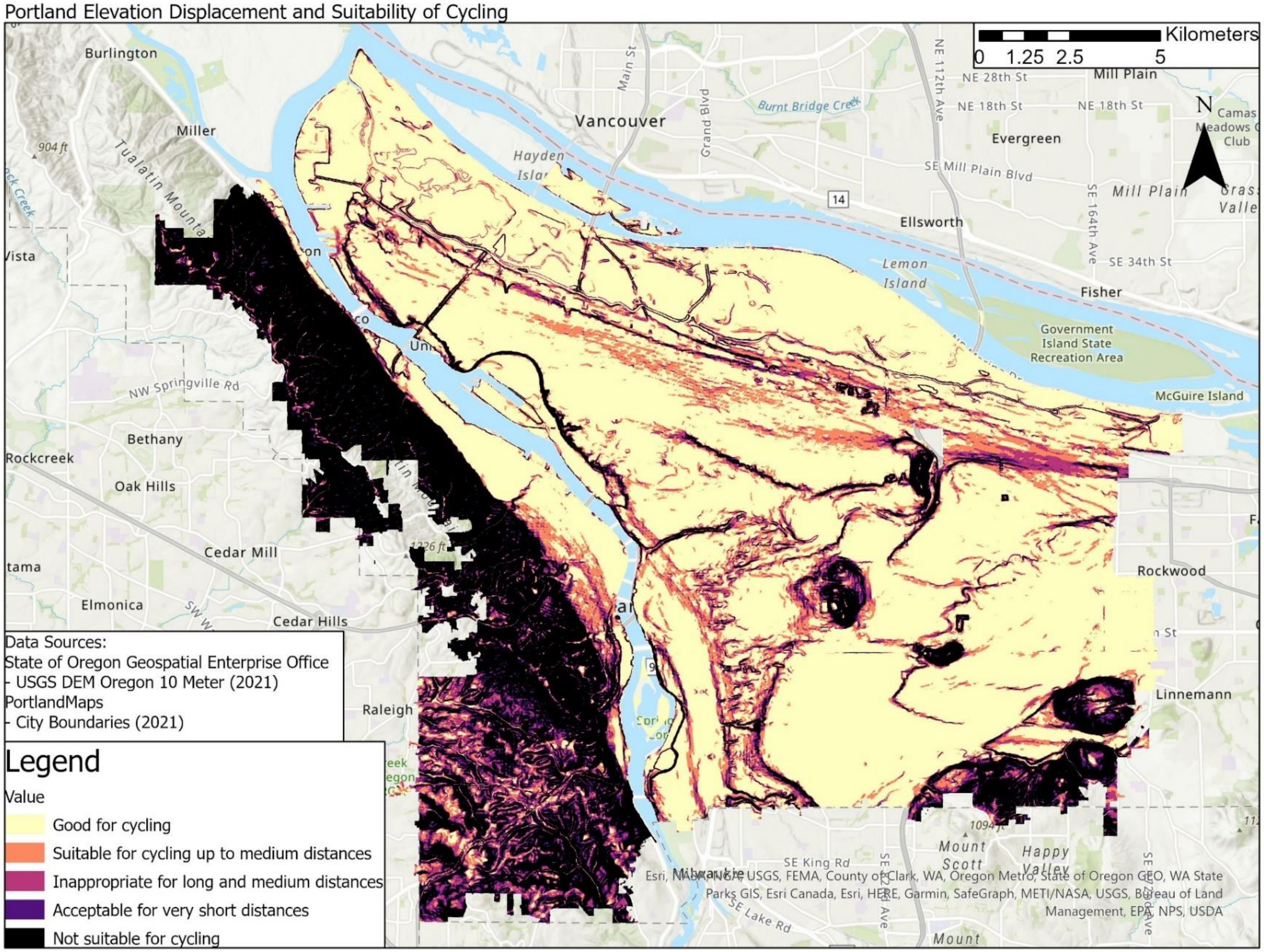


Figure 20 - Gradient of Portland

The following graph (Figure 21) summarizes the city-wide topographic changes for each case study city according to the gradient ranges outlined in Table 12. The data are presented in bins of slopes observed along the horizontal axis, with the frequency of observations in each city plotted as the vertical axis.

As discussed, Portland has the highest proportion of its area (54.1%) containing a 0-3% gradient range, which is the is most desirable for cycling. This rate demonstrates that if a cyclist were to travel between any two points of Portland, there is a 54.1% chance of travelling on a flat surface and offers the highest cycling comfort. For the 3-5% gradient range, suitable for cycling medium distances, Vancouver and Waterloo have higher proportion belonging to this category than Portland and Madison. When considering the combination of the 0-3% and 3-5% gradient range into the suitability analysis, the results show that Portland, Waterloo, and Vancouver, are cities that are most suitable for cycling because a high proportion of their city areas, with 64.3%, 53.2%, 40.5%, being spaces that are suitable for cycling. Madison's topography proves to be the most challenging for cyclists because only 22.1% of the city's areas are suitable or moderately suitable for cycling. The topography of Madison is especially difficult for cyclists when 47.8% of the city's area is over 10% in slope and not suitable for cycling. The results then imply that cyclists travelling in disparate sections of Madison will likely involve a segment with a very steep slope.

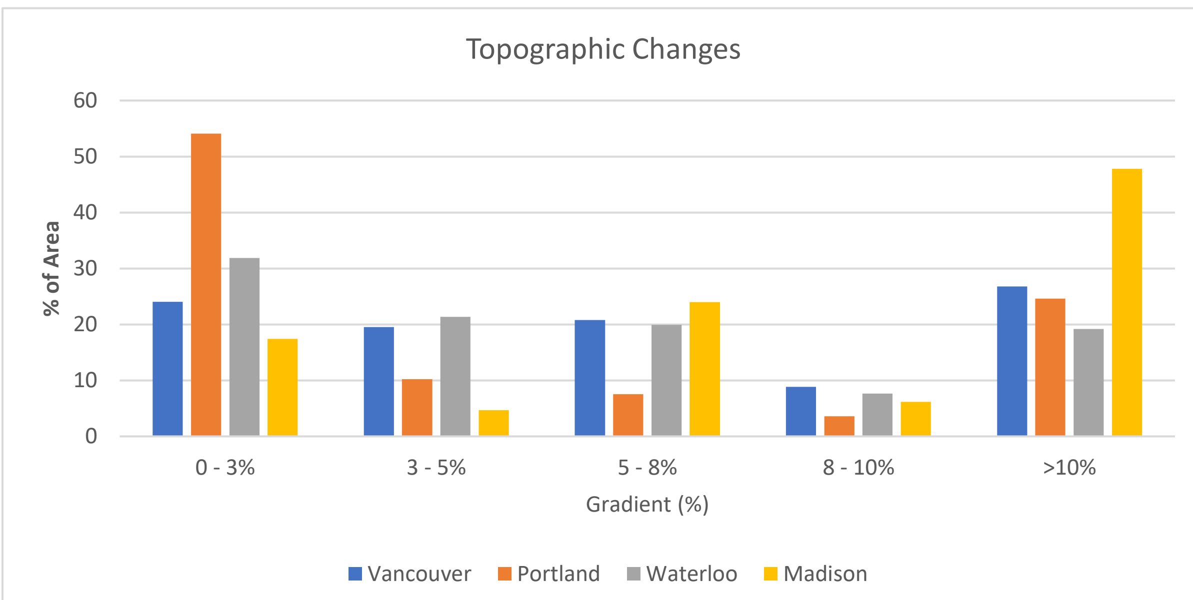


Figure 21 - City-by-city comparison of the topographic changes in percent grade

4.2.2.2 Bicycle Network Elevation Changes

While the previous analysis examined all the land area within the cities' boundaries, there is value in assessing the elevation changes that exist along designated cycling paths. This assessment is shown here.

The analysis of the bicycle network elevation changes follows the categories set out in Table 12 to determine if the cycling networks of case study cities are suitable for cycling. The results show that about 20% of the total length of bicycle facilities in Portland and Madison in fact contain the highest range of slope (Figure 26), thereby creating barriers for stimulating interest for cycling. Although it is more common to find places with a gentle slope in Portland, the cycling routes are in fact located in places with a high elevation displacement. Similarly, Madison has a significantly high proportion of steep slopes along bicycle facility segments (Figure 22, Figure 25), which suggest cyclists may be deterred from cycling.

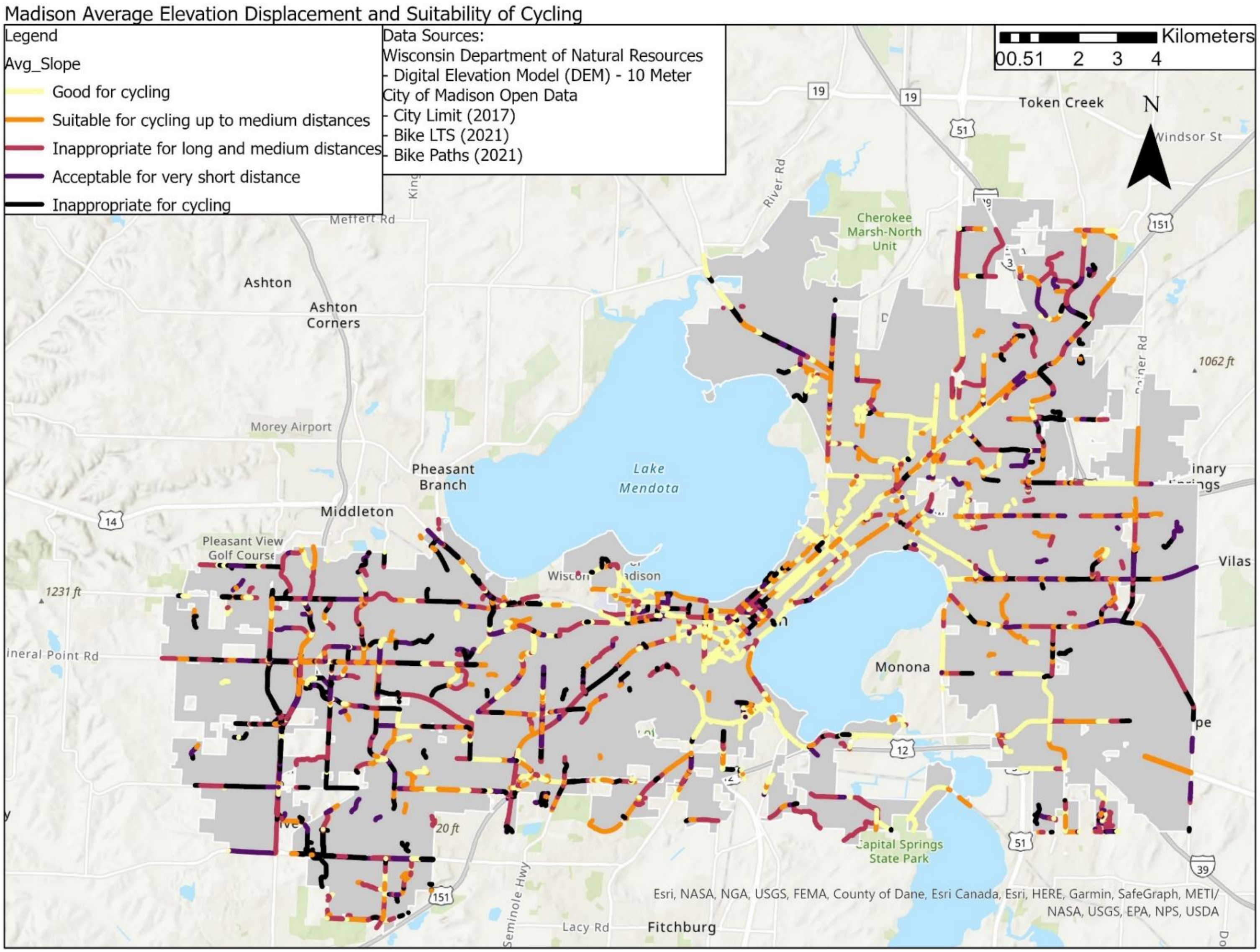


Figure 22 - Elevation Changes on Madison's bike routes

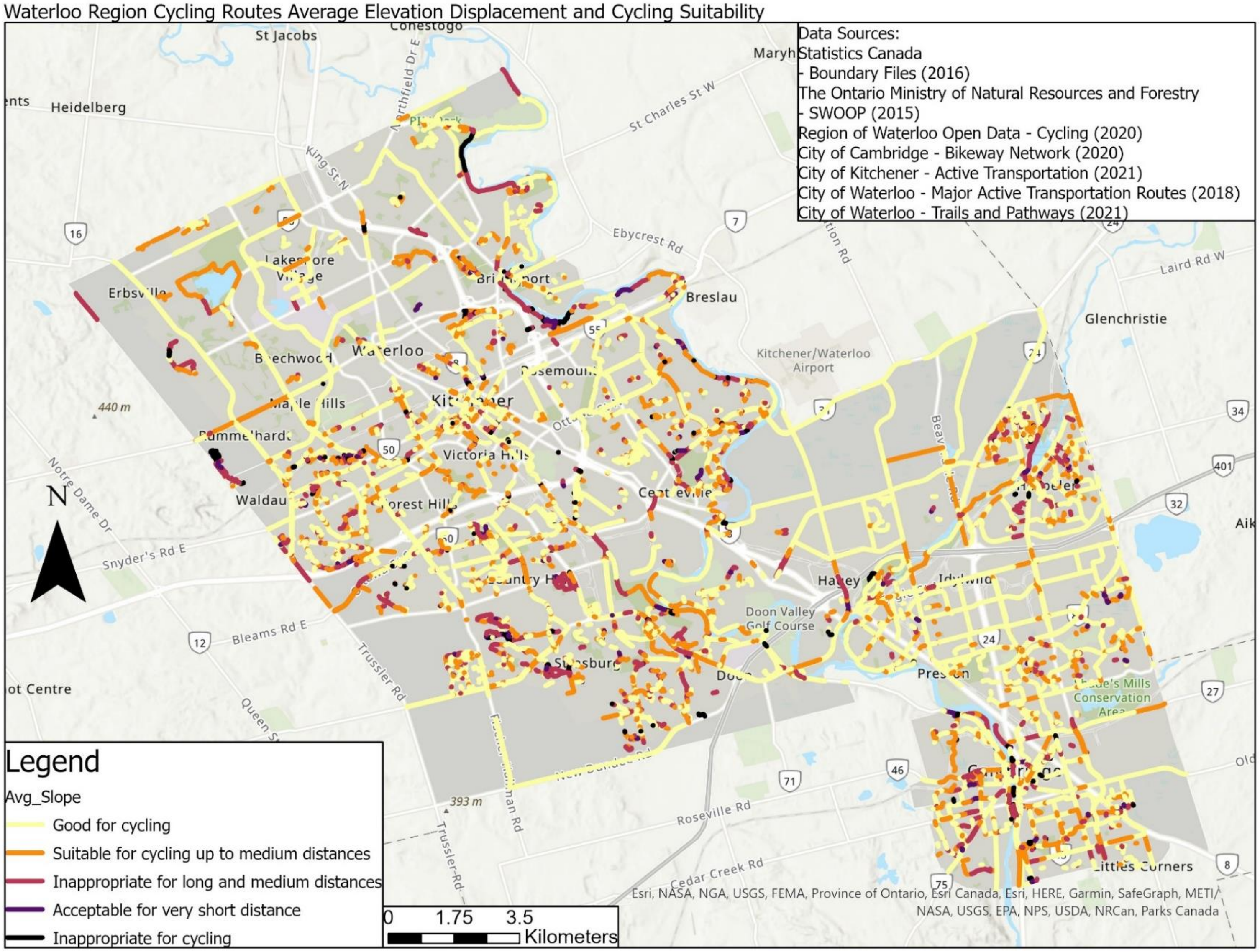


Figure 23 - Elevation Changes on Waterloo's bike routes

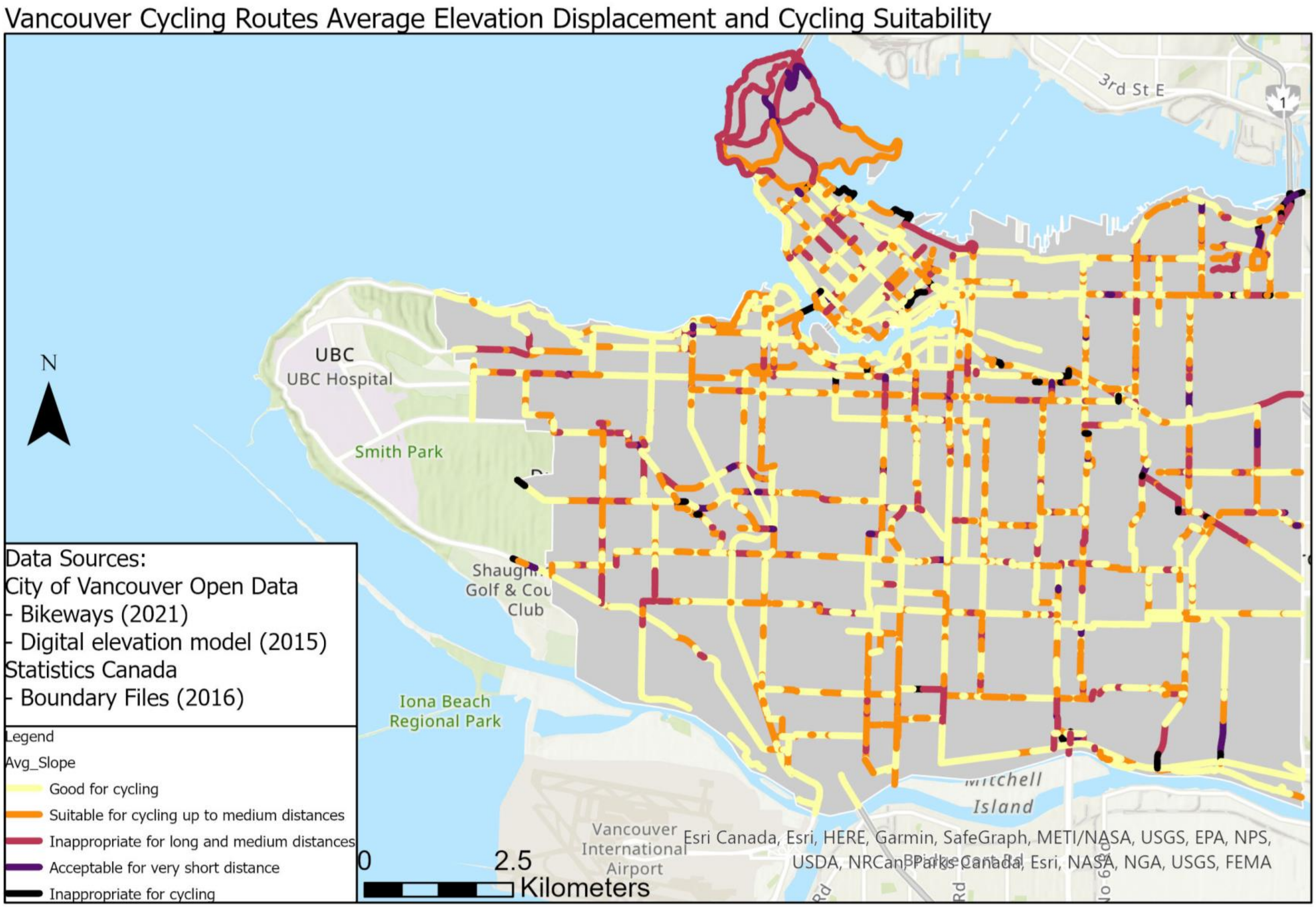


Figure 24 - Elevation Changes on Vancouver's bike routes

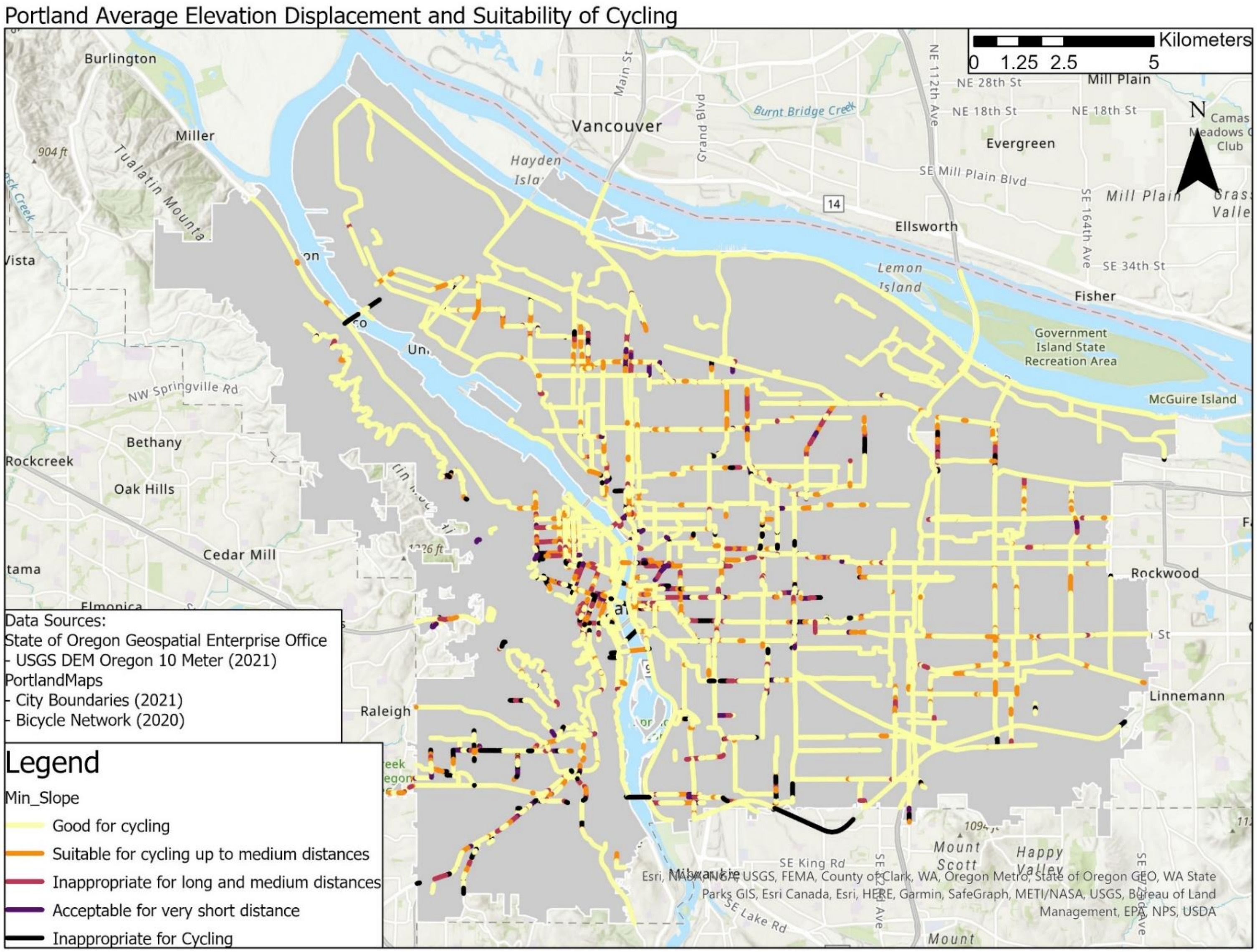


Figure 25 - Elevation Changes on Portland's bike routes

On the other hand, the topographies along cycling routes in Vancouver and Waterloo present fewer barriers to cycling in these cities. Figure 23 and Figure 24 show maps of Vancouver and Waterloo with the elevation changes of their cycling facilities demonstrating that a much smaller proportion of their networks contain a level of steep slope that deters cyclists as compared with Portland and Madison. Moreover, with 49% of Vancouver and 52% of Waterloo's cycling network containing little to no slope, the cycling networks of both cities will certainly be comfortable for cyclists The high percentage of their cycling networks belonging to this category demonstrates that both Vancouver and Waterloo have concentrated their investments in cycling facilities to places where the topography does not pose as a barrier for cycling.

The following chart (Figure 26) summarizes the average slope of bicycle route segments for each case study cities according to the categories set out in Table 12. The results from the category representing surfaces containing slopes that are the most suitable for cycling, 0-3% gradient, shows that the cycling networks in Vancouver and Waterloo are likely to be most conducive to cycling, with 49% and 37.1% of their respective networks containing 0-3% slopes. However, the cycling networks of Portland and Madison are less ideal for cyclists because 21% of Portland and 19% of Madison's bike networks contain slopes that are unfavourable for cycling, whereas only 2.8% and 2% of Vancouver and Waterloo's cycling facilities are not suitable for cycling.

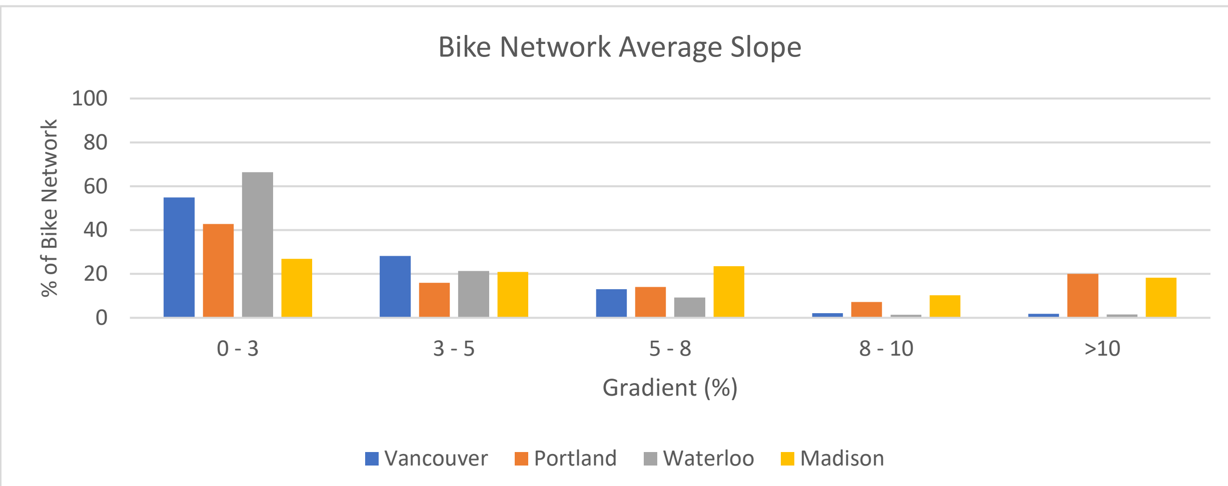


Figure 26 - A comparison of the average slopes in each segment of cycling facilities in each city

4.2.2.3 Summary

The following Table 13 - Summary of topographic statistics further summarizes the findings of topographic analysis in each case study city. While the city-wide and bicycle network topographic analysis generated some apparently contradictory results, the following table attempts to present a synthesized conclusion to allow for the comparison between the cities. The results present that Portland contains a topography that offers the most comfort for cyclist, but some sections of the bike network may still involve steep slopes that presents challenges to cycle. The topographies of Vancouver and Waterloo can be assumed to have produced some impact towards the desirability of cycling in their cities. Because Vancouver has most of its cycling network contained in the flat area, the topography does not create significant barriers to cycling. The result from Waterloo also demonstrates that most of their cycling networks are in areas with little to no slopes, which makes it possible for more individuals with different abilities to cycle. However, the topography of Madison appears to induce significant negative impact towards cycling. Because

Madison's topography involves high rates of vertical displacement in many places within the city limits, the placement of cycling routes has also been significantly impacted and cause challenges for cyclists.

Table 13 - Summary of topographic statistics

Account	Vancouver, BC	Portland, OR	Waterloo, ON	Madison, WI
Built Environment	●	●	✕	✕
Topography	▲	●	▲	✕

Legend:
Supportive for Cycling: ●
Supports Cycling Partially: ▲
Not Supportive for Cycling: ✕

4.2.3 Bicycle Network Connectivity and Density

4.2.3.1 Bicycle Network Connectivity

The analysis of the connectivity of the bicycle networks in the case study cities revealed that Vancouver's and Portland's bicycle networks are the most connected. Although cycling is a mode of transport that may allow for flexibility in route choice – via a designated cycle path or on a route without such a facility – this decision is normally thought to depend on confidence of cyclists. Cyclists with a high confidence are often regular cyclists who tend to choose the most direct path between origin and destination. Cyclists with less confidence are usually less experienced cyclists who may elect to choose longer paths to have access to designated facilities which offer better perceived and actual safety.

With the aim of this research being to examine the suitability of cycling in cities for all ages and abilities, it will certainly be important to consider how far cyclists can travel without exiting the cycling network. Figure 27 shows the numbers of origins and destinations zones that can be accessed within each city through direct connections on a cycling path. The results demonstrate that more than 89% areas in Vancouver and 42% of areas in Portland are directly connected by the bicycle network. This strong relative connectivity suggests a high level of comfort to cycle across those cities. In contrast, the cycling network in Waterloo and Madison connect to a much smaller proportion of the city, which can make cycling difficult.

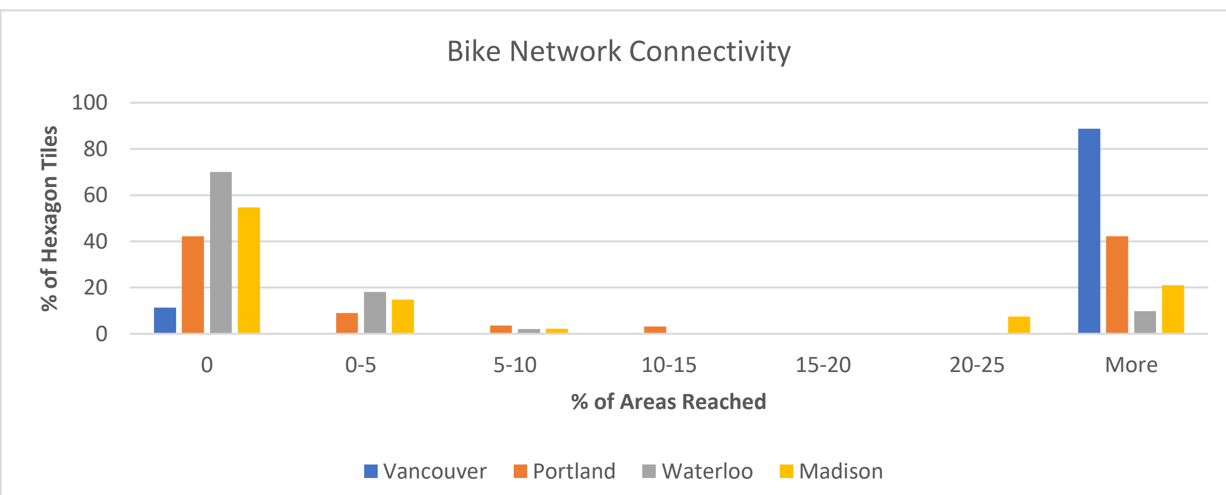


Figure 27 - The connectivity of the bicycle networks in the case study cities

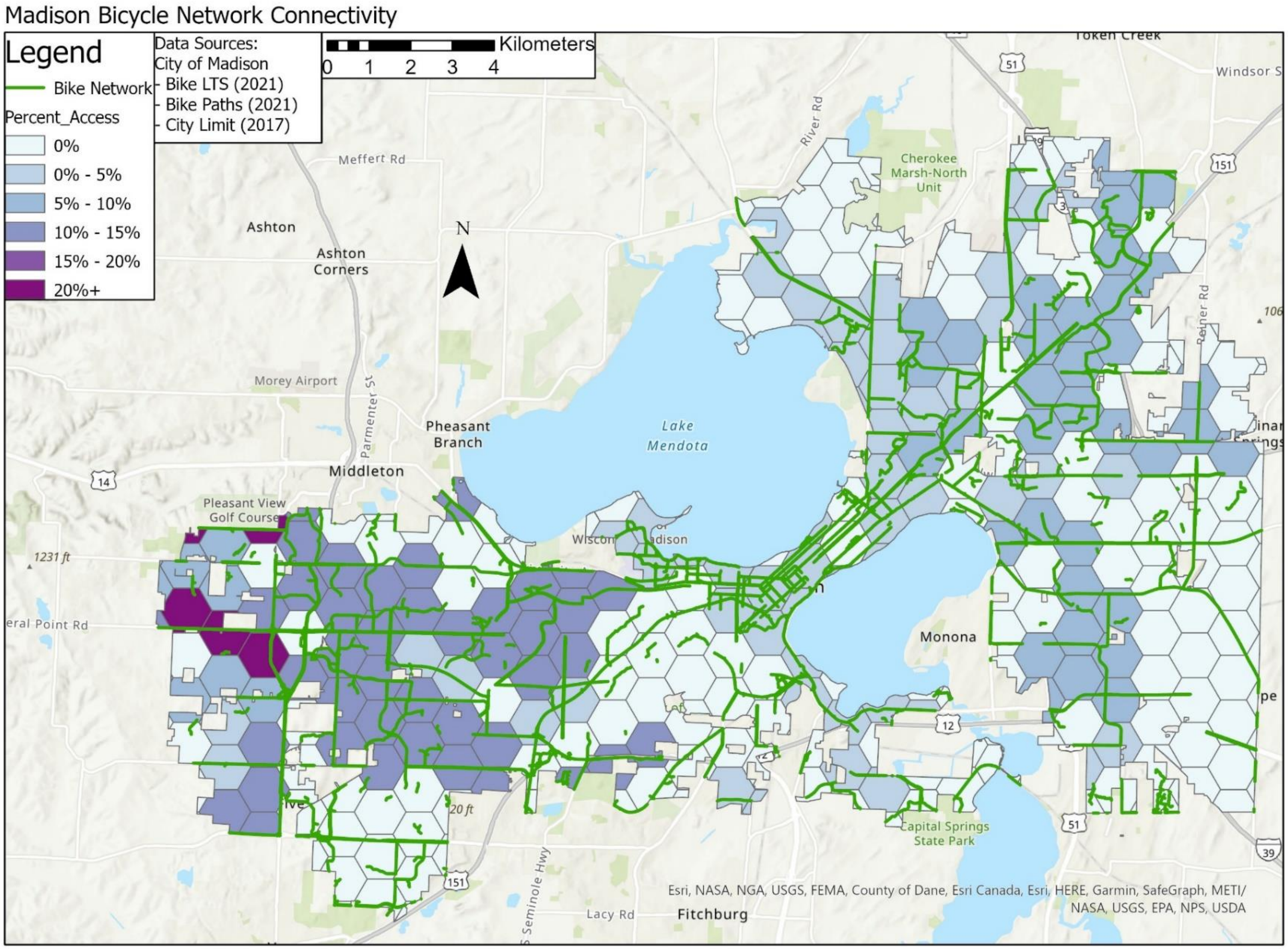


Figure 28 - The Connectivity of Madison’s Bicycle Network by Percent of Accessible Areas

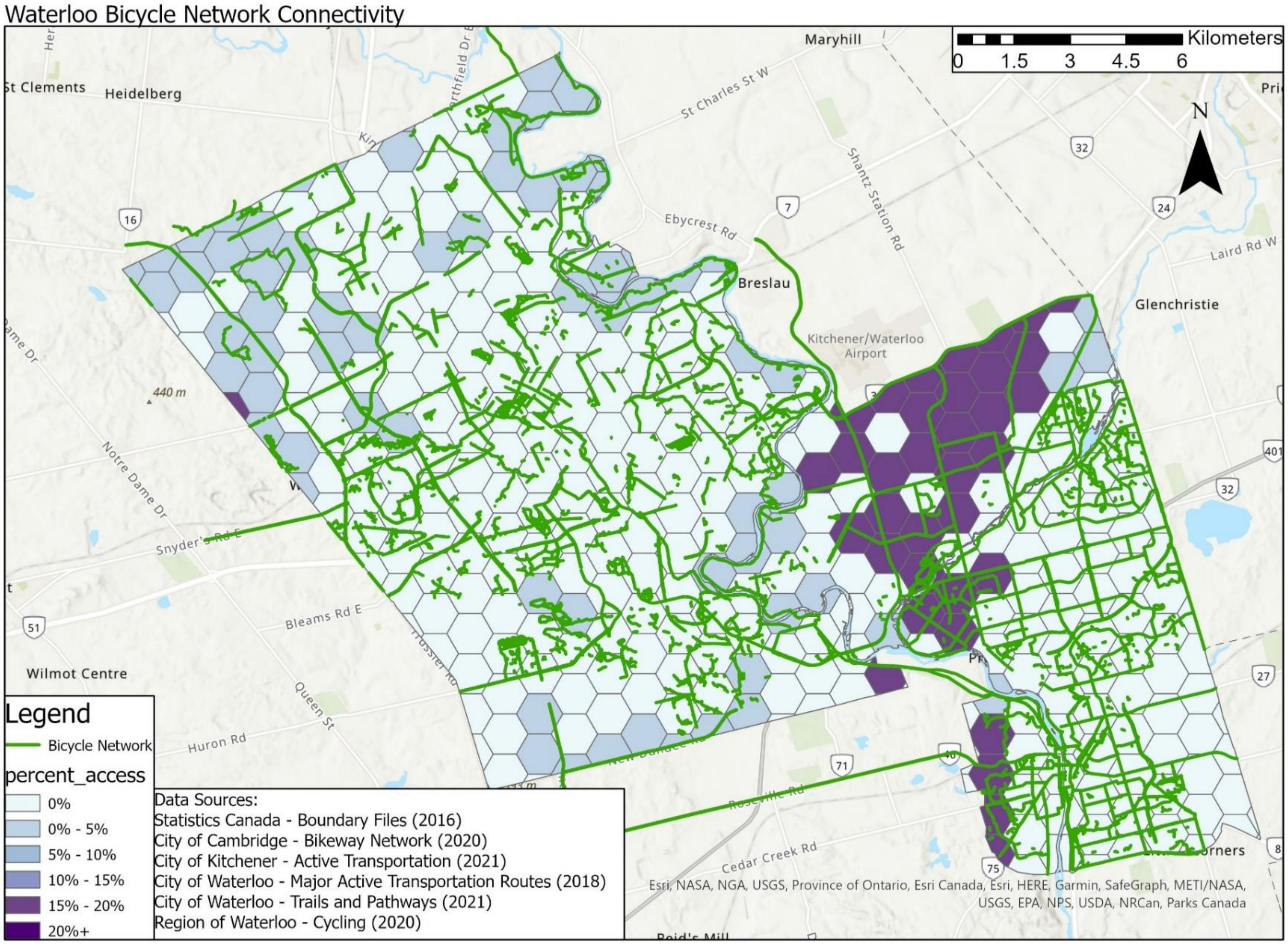


Figure 29 - The Connectivity of Waterloo's Bicycle Network by Percent of Accessible Areas

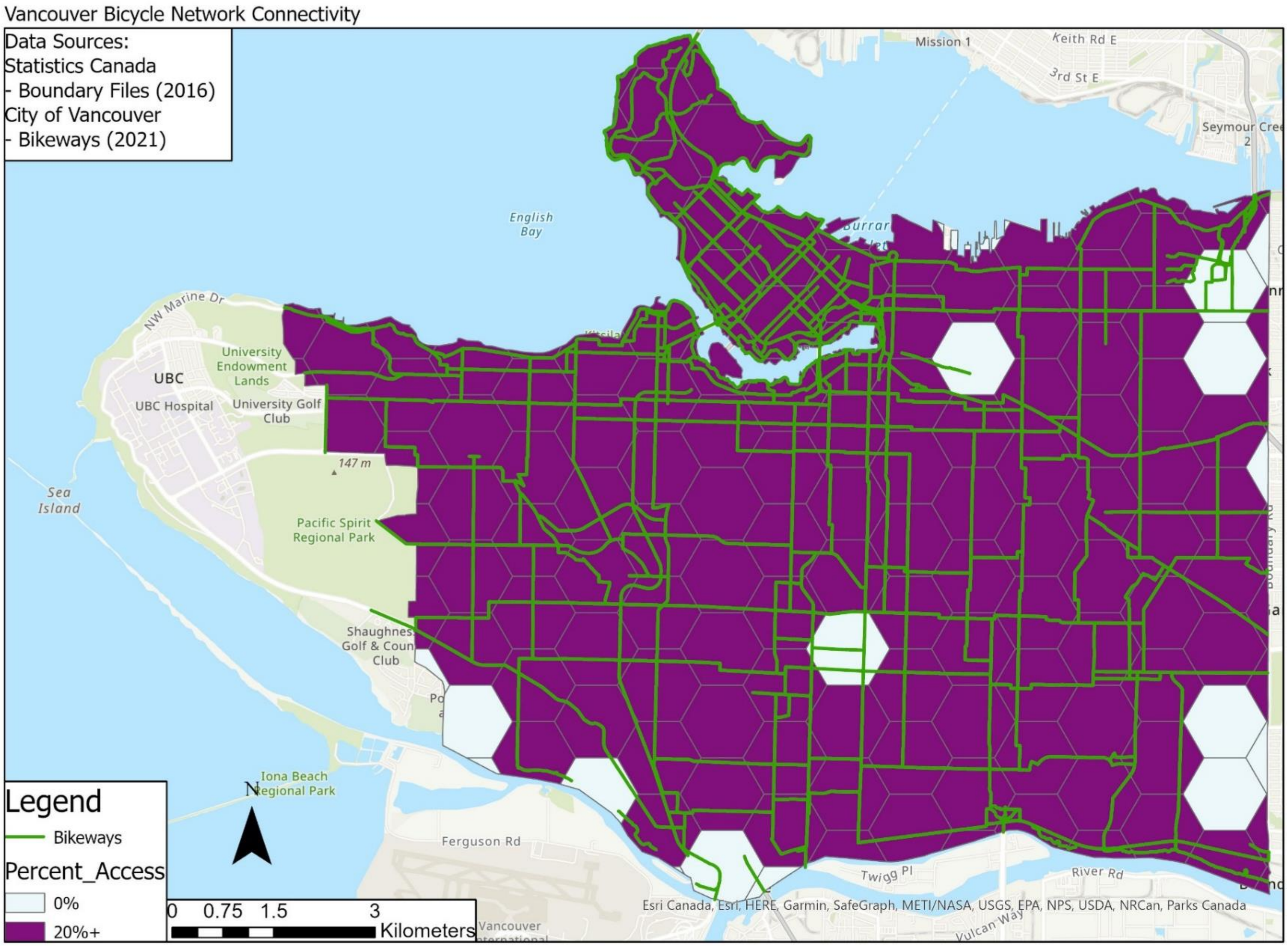


Figure 30 - The Connectivity of Vancouver's Bicycle Network by Percent of Accessible Areas

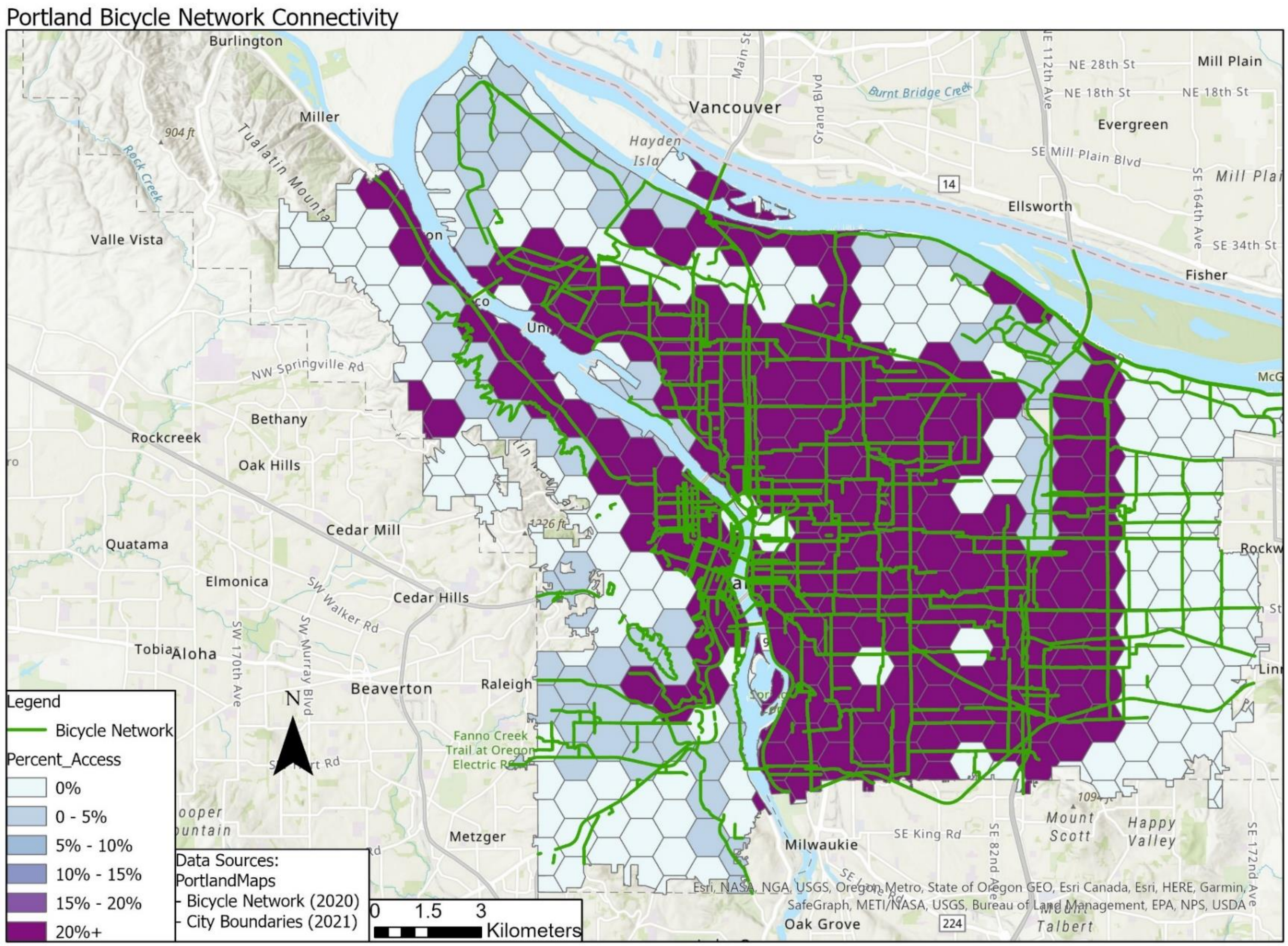


Figure 31 - The Connectivity of Portland's Bicycle Network by Percent of Accessible Areas

4.2.3.2 Bicycle Network Density

A second analysis used to assess the prevalence of bike facilities is to measure distribution of the lengths of cycling routes within disaggregated spatial areas in the case cities. The results from this analysis, presented in Figure 32 demonstrate that the bicycle networks in Vancouver, Waterloo, and Madison are conducive to cycling by providing widespread connectivity along dedicated networks. Since very few of the areas within Vancouver, Waterloo, and Madison contain no cycling facilities, it demonstrates that most people in the cities could access cycling facilities within a kilometre from their origin or destination. However, large areas in Portland remain to be connected with cycling facilities, which may hinder the desirability of cycling.

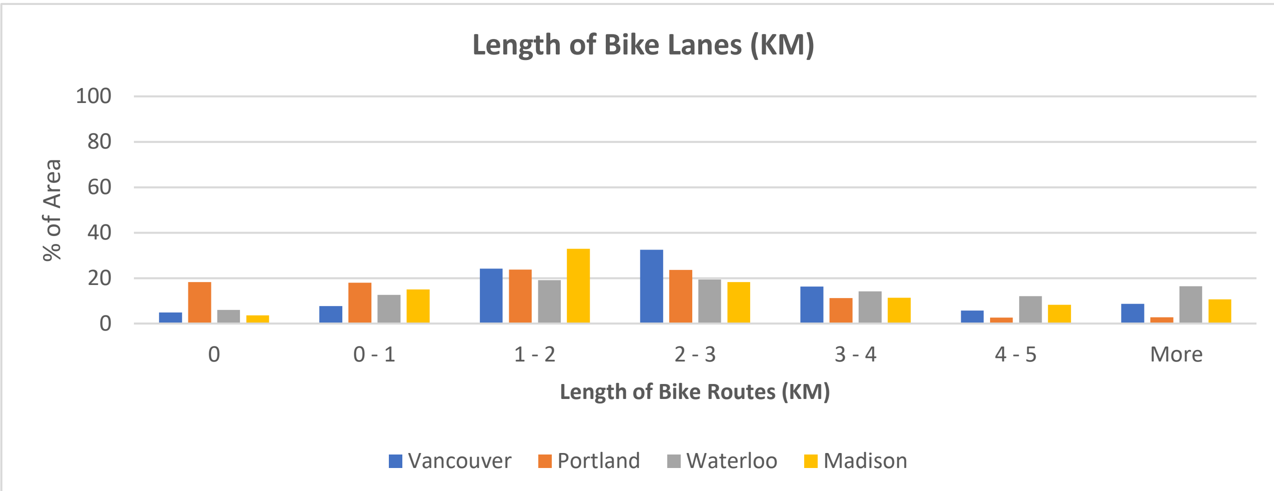


Figure 32 - Proportion of hexagon tiles containing a length of cycling routes

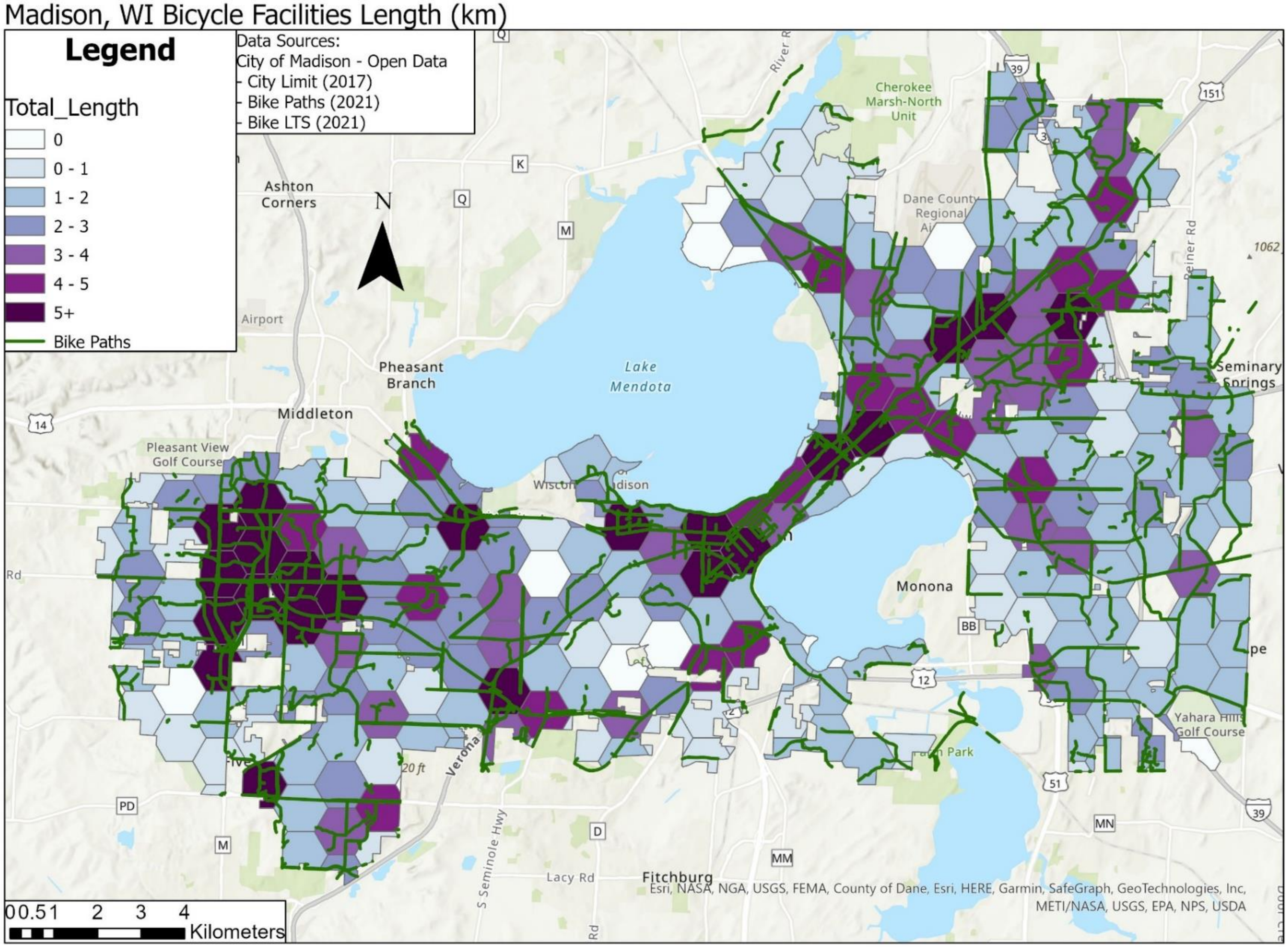


Figure 33 - Density of Bicycle Facilities by Length in Kilometers (Madison, WI)

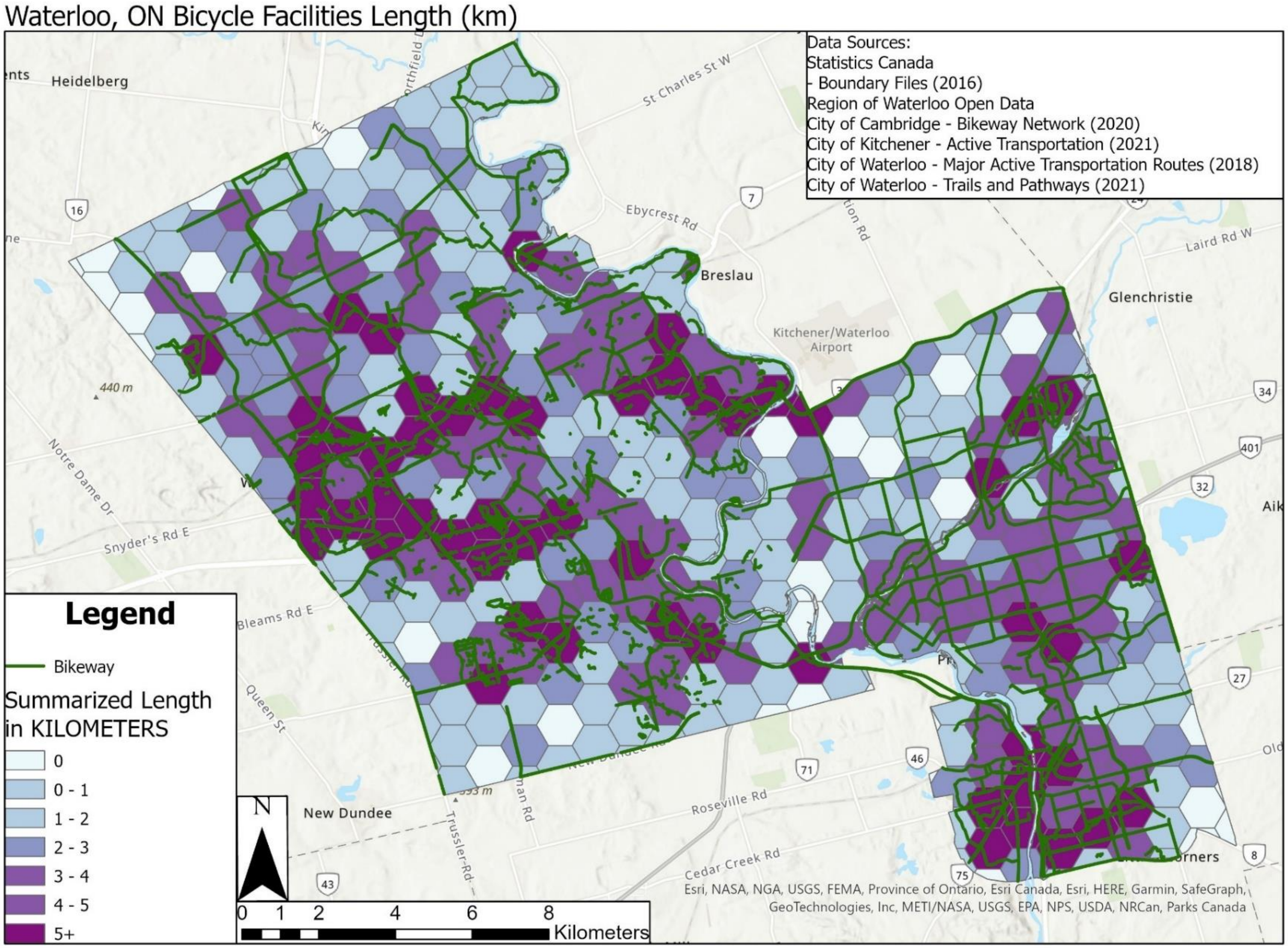


Figure 34 - Density of Bicycle Facilities by Length in Kilometers (Waterloo, ON)

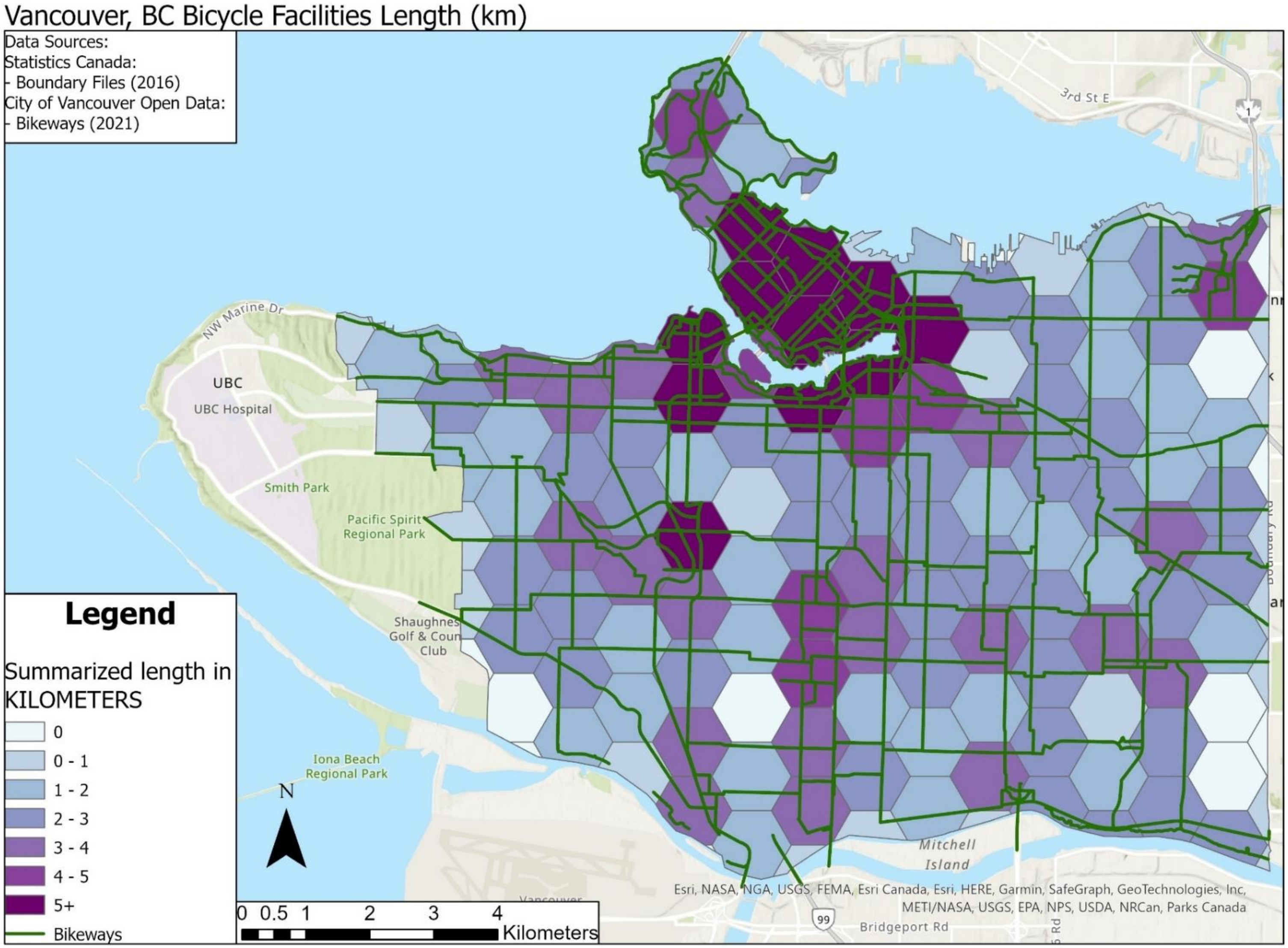


Figure 35 - Density of Bicycle Facilities by Length in Kilometers (Vancouver, BC)

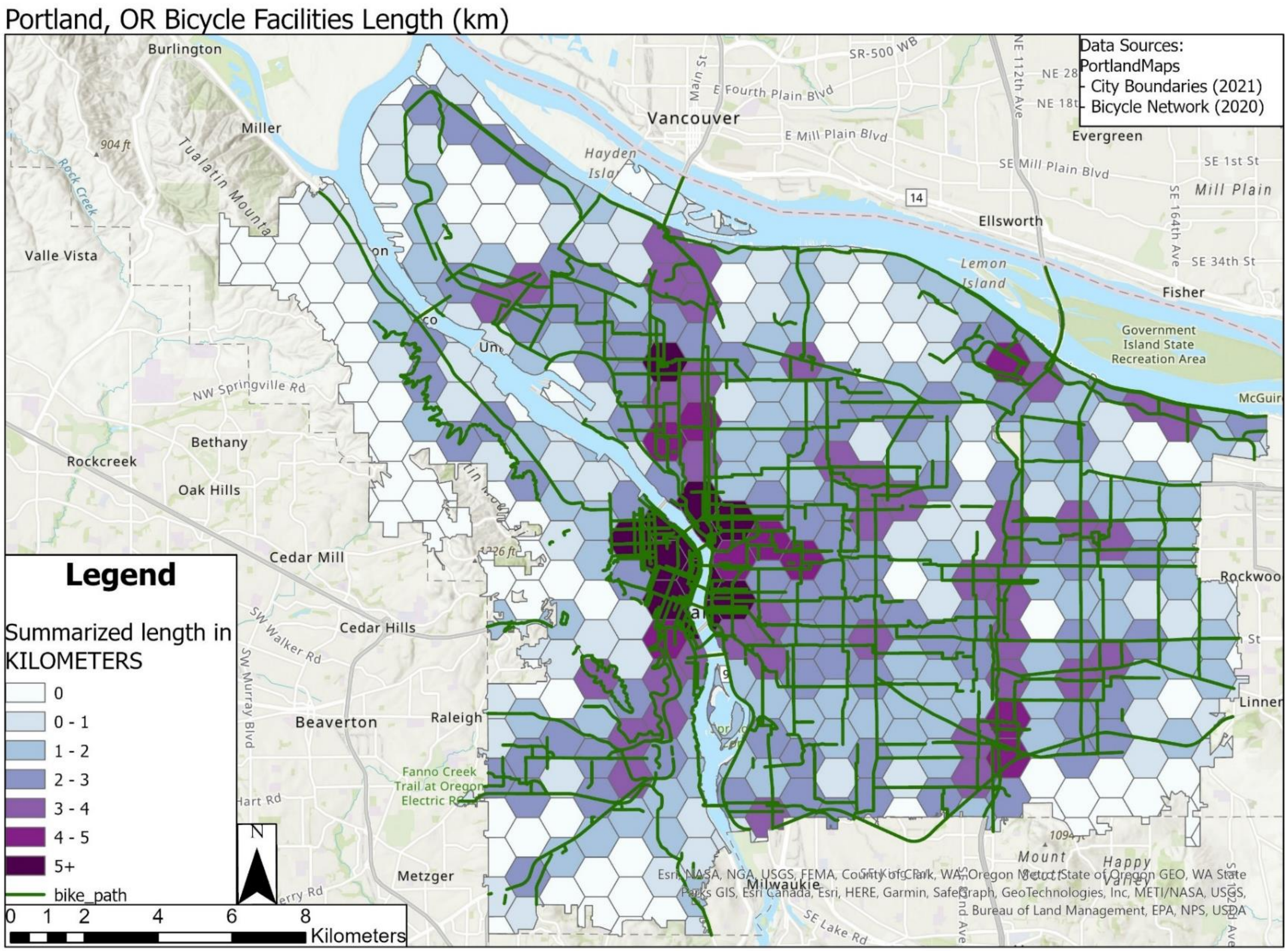


Figure 36 - Density of Bicycle Facilities by Length in Kilometers (Portland, OR)

4.2.3.3 Summary

The following table summarizes the suitability of cycling scores for each case study city based on the connectivity and density of their cycling facilities. The results of both the bicycle network connectivity and cycling routes density show that Portland has the cycling network that offers the most accessibility to cyclists because travelling on the cycling network can bring you to most other places within the city. Vancouver is also another city that contains a bicycle network that is moderately conducive to cycling because the proportion of areas with no cycling connection is low and cyclists can travel to a high proportion of all other parts of the city. However, Waterloo and Madison's cycling networks are not conducive to cycling because cyclists travelling on them can only reach a limited number of other spaces and some of their areas have little to no access to cycling facilities.

Despite the low connectivity of cycling network and the lack of access to cycling facilities in some areas of Madison, the network can be categorized as moderately conducive to cycling because it has a high density of cycling routes.

Table 14 - Summary of the Bike Network Connectivity and Density attribute

Account	Vancouver, BC	Portland, OR	Waterloo, ON	Madison, WI
Built Environment	⬤	⬤	✕	✕
Topography	▲	⬤	▲	✕
Bike Network	▲	⬤	✕	▲

Legend:
Supportive for Cycling: ⬤
Supports Cycling Partially: ▲
Not Supportive for Cycling: ✕

4.2.4 Climate

4.2.4.1 Temperature

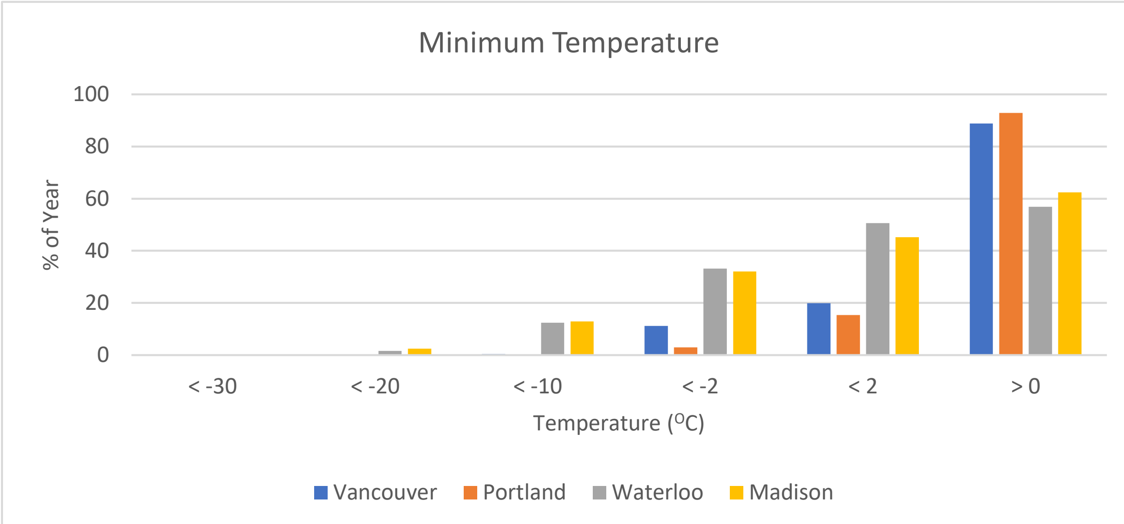


Figure 37 - Annual Percentage of days with Minimum Temperatures

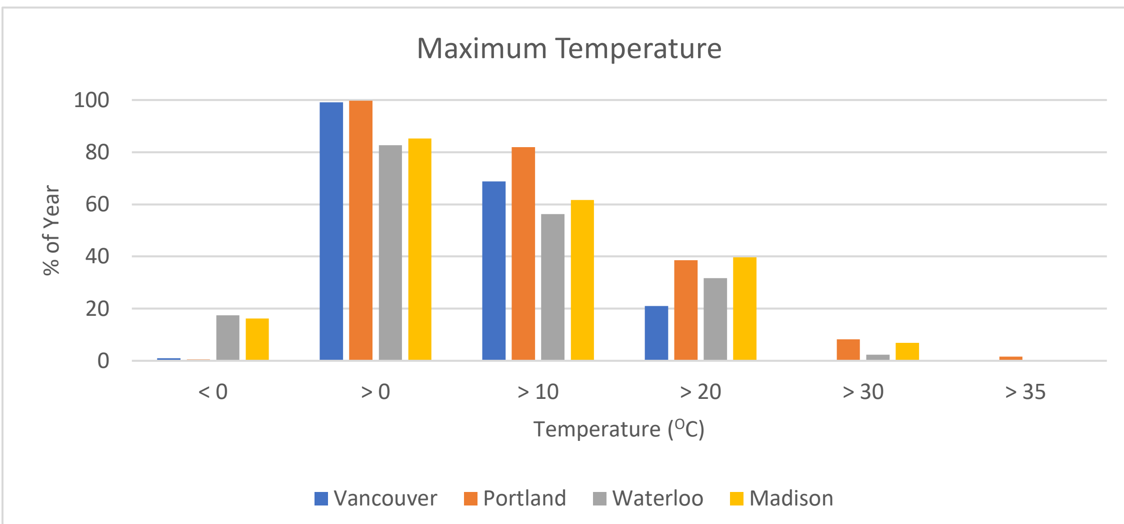


Figure 38 - Annual Percentage of days with Maximum Temperatures

Recall that the literature suggests that cycling is considered to be best suited to days when the maximum temperature remains below 25^{O}C, where the minimum remains above 5^{O}C and where the quantity of precipitation is low or none. Because the data sources available for this analysis only disaggregated observed temperatures in ranges of 10 ^{O}C, in my assessment, I used 0 ^{O}C and 30 ^{O}C as the “suitable temperature” boundaries.

The results of analyzing the weather patterns of the case study cities revealed that Portland and Vancouver experience the best climate for cycling. The temperature ranges normally experienced in these cities are regularly within the boundaries. Figure 38 reveals that only 8.2% of a year in Portland, and 0.1%

of a year in Vancouver, experience maximum temperatures above 30 ^{O}C, which suggest that temperature should not be a substantial obstacle to cycling.

The temperature profiles are most problematic in Waterloo and Madison where residents experience significantly numbers of days where the minimum temperature is below 0^{O}C. With only 62.4% of a year in Madison, and 56.9% of a year in Waterloo experiencing a minimum temperature of above 0^{O}C, frequent cold may be a natural impediment to cycling. Beyond the cold, Waterloo and Madison also experience some days with high heat. Waterloo has 2.3% of a year and Madison 6.9% of a year with maximum temperatures of above 30 ^{O}C; these high heat days also reduce the propensity for people to experience cycling-suitable temperatures. Therefore, the climate in both Waterloo and Madison are not conducive to cycling.

4.2.4.2 Precipitation

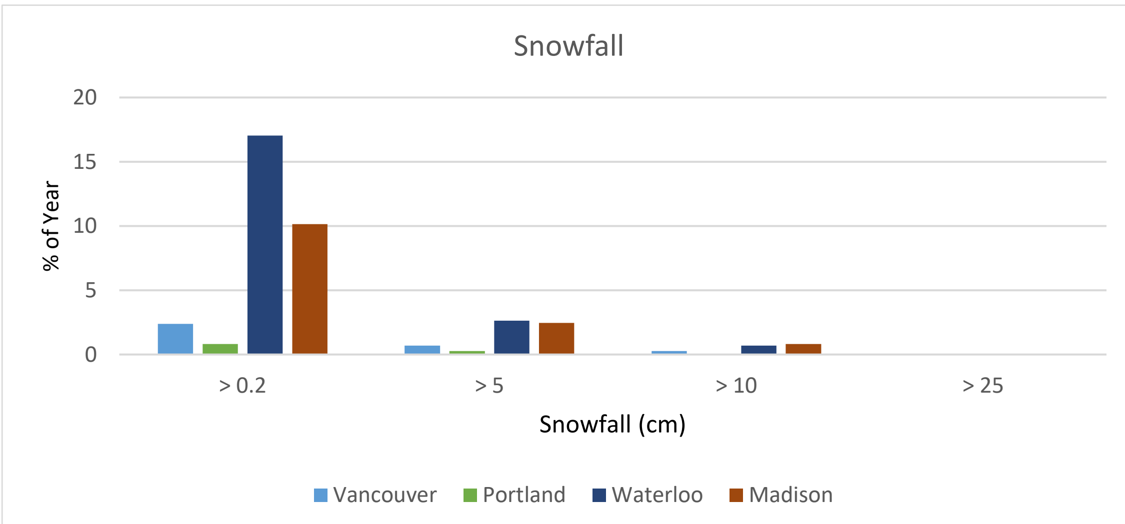


Figure 39 - Annual Percentage of days with precipitation

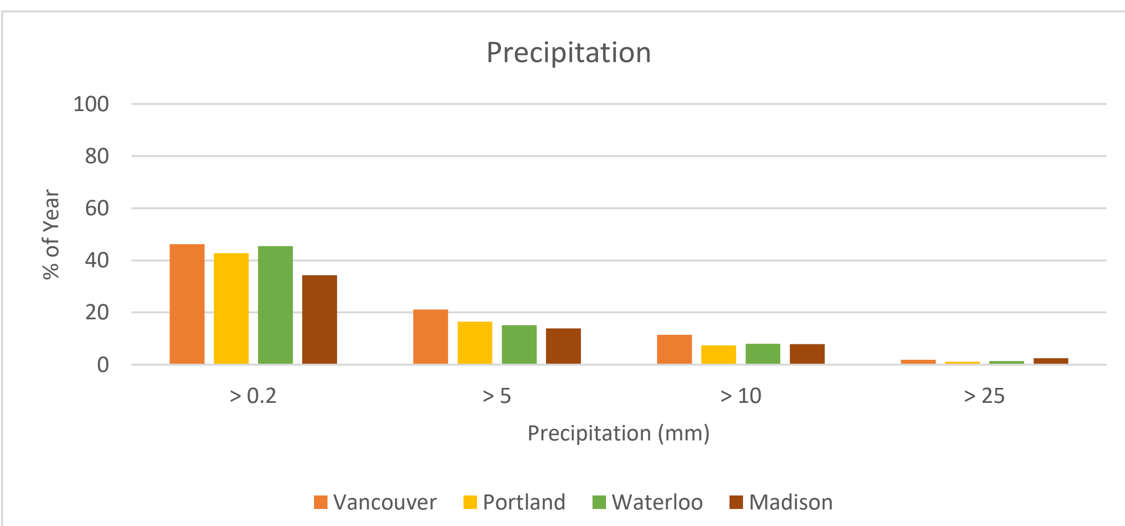


Figure 40 - Annual Percentage of days with snowfall

The analysis of the level of precipitation in the case study cities reveals that Portland, Waterloo, and Madison experience a relatively low amount of precipitation in a year, which may suggest that these cities have a natural advantage for cyclists. In contrast, cycling could be made difficult in Vancouver because of its higher rate of precipitation. With cycling being a mode of transport that involves a largely outdoor journey with minimal covering, the amount of precipitation could have large impacts on the desirability of cycling.

While Waterloo and Madison tend to have overall fewer days with precipitation, these cities experience significant more snowfall than the other case cities. If an efficient snow removal plan is not in place, the obstacles along the designated cycling paths could pose challenges that may deter cyclists.

4.2.4.3 Summary

The following table summarizes the suitability scores of the case study cities based on the results of the climatic analysis. The city that has the best climate to support the comfort of cyclists is Portland. The rating was awarded because most of the year in Portland is within the ideal temperature range for cycling and it has the lowest proportion of the year among the case study cities to have precipitation. Despite having similar temperature range as Portland, Vancouver has a slightly lower rating in its climatic suitability for cyclists. The decline in suitability happens because of the high rates of rainfall, which makes the cyclists' journeys more unpleasant. The climate in Waterloo and Madison tends to be more volatile and experience fewer days with temperatures and precipitation that are ideal for cyclists. Both Waterloo and Madison experience weather that is not ideal for cycling because they both receive high rates of snowfall in winter and high temperatures in summer, which create more inconveniences to cyclists.

Table 15 - Summary of Climate attribute

Account	Vancouver, BC	Portland, OR	Waterloo, ON	Madison, WI
Built Environment	⬤	⬤	✕	✕
Topography	▲	⬤	▲	✕
Bike Network	▲	⬤	✕	▲
Climate	▲	⬤	✕	✕

Legend:
Supportive for Cycling: ⬤
Supports Cycling Partially: ▲
Not Supportive for Cycling: ✕

4.2.5 Demographics

The demographics analysis of the case study cities revealed that populations in Waterloo and Madison have a high proportion of youth and post-secondary students (Table 16). Since the youth population (Winters et al., 2010) and post-secondary students (Chaney et al., 2014) are found to be the age group with the highest frequency of cycling activity, having a large proportion of this population group may suggest a greater propensity to cycle in these cities. With both the proportion of post-secondary students and youth being important indicators of cycling potentiality, the results will be informed by a combination of both statistics. The number of post-secondary students and youth population are found to be lower in both Vancouver and Portland, which leads to an outcome that, everything else equal, the rate of cycling in those cities may be lower. However, Waterloo and Madison have a much younger population with many students attending post-secondary students in their vicinity, they are more likely to stimulate greater interests to cycling.

Table 16 - Youth population and post-secondary enrolment in each case study cities

Comparable	Vancouver, BC	Portland, OR	Waterloo, ON	Madison, WI
15-34 Population	197,615 (31.3%)	197,141 (30.6%)	132,000 (36.3%)	109,737 (43.0%)
Post-Secondary Enrolment	79,126 (12.1%)	53,402 (19.9%)	50,305 (13.8%)	50,961 (20.9%)

Table 17 - Summary of Demographic attribute

Account	Vancouver, BC	Portland, OR	Waterloo, ON	Madison, WI
Built Environment	●	●	✕	✕
Topography	▲	●	▲	✕
Bike Network	▲	●	✕	▲
Climate	▲	●	✕	✕
Demographics	▲	▲	●	●

Legend:

Supportive for Cycling: ●

Supports Cycling Partially: ▲

Not Supportive for Cycling: ✕

4.3 Summarized Comparison with Observed Mode Shares

4.3.1 Vancouver, BC

The results of the quantitative analysis for all physical attributes of the City of Vancouver reveal that they are moderately conducive to cycling (Table 18), which should correlate to the existence of some regular cycling activities. The physical characteristic of Vancouver that best supports cycling activities is its built environment. With the quantitative data showing that all other attributes for Vancouver resulted in partial support for cycling activities, it demonstrates that cyclists may not be entirely comfortable in cycling in the city. Despite having a physical environment that only partially supports cycling activities, the observed rate of cycling remains high, which makes evident some discrepancies between the expected and observed cycling rates.

Table 18 - Summary of Attribute Scores for Vancouver

Account	Vancouver, BC
Built Environment	●
Topography	▲
Bike Network	▲
Climate	▲
Demographics	▲
Expected Cycling Interests	Medium
Recent Cycling Mode Share	6.1%

4.3.2 Portland, OR

The results of the quantitative analysis for all physical attributes of the City of Portland reveals that they are very conducive to cycling and the results should reflect a very high rate of cycling. Four of the five physical attributes considered in the quantitative analysis in fact reflect that Portland contains the key elements to support cycling activities in the city. Although Portland lacks the adequate youth and student population to help make cycling popular, despite these demographics barriers to support the popularization of cycling, the expectation of a high cycling rate in Portland is matching with the high observed cycling rate.

Table 19 - Summary of Attribute Scores for Portland

Account	Portland, OR
Built Environment	●
Topography	●
Bike Network	●
Climate	●
Demographics	▲
Expected Cycling Interests	High
Recent Cycling Mode Share	6.4%

4.3.3 Waterloo, ON

The results of the quantitative analysis for all physical attributes of the Region of Waterloo, ON reveals that they are not conducive to cycling and should result in a low cycling rate. The quantitative analysis results show that the built environment, bicycle network, and climate, in Waterloo are in fact not contributing to cycling activities in the city. However, with the city's moderately flat topography and large student population, hope remains in the future to support greater cycling activities. As a result, the expected cycling rate for Waterloo is low and that very few people in the city are anticipated to cycle regularly. The observed rate of cycling in fact matches the expected low cycling rate.

Table 20 - Summary of Attribute Scores for Waterloo

Account	Waterloo, ON
Built Environment	✕
Topography	▲
Bike Network	✕
Climate	✕
Demographics	●
Expected Cycling Interests	Low
Recent Cycling Mode Share	1.2%

4.3.4 Madison, WI

The results of the quantitative analysis for all physical attributes of the City of Madison, WI reveal that they are not conducive to cycling and should result in a low cycling rate. The quantitative analysis reveals that the built environment, topography, and climate, of Madison do not motivate cycling because they do not offer comfort to cyclists. However, the high connectivity and density of its cycling network and high youth and student population may still support the city to develop a habit of cycling. Because of the challenges posed by most physical attributes, Madison is expected to perform relatively poorly in its observed cycling rate. However, the observed cycling rate is much higher than the expected rate; this large discrepancy warrants careful consideration of the steps Madison has taken to achieve this outcome.

Table 21 - Summary of Attribute Scores for Madison

Account	Madison, WI
Built Environment	×
Topography	×
Bike Network	▲
Climate	×
Demographics	●
Expected Cycling Interests	Low
Recent Cycling Mode Share	5.3%

4.3.5 Summary

Table 22 - Summary of Quantitative Results

Account	Vancouver, BC	Portland, OR	Waterloo, ON	Madison, WI
Built Environment	●	●	×	×
Topography	▲	●	▲	×
Bike Network	▲	●	×	▲
Climate	▲	●	×	×
Demographics	▲	▲	●	●
Expected Cycling Interests	Medium	High	Low	Low
Recent Cycling Mode Share	6.1%	6.4%	1.2%	5.3%

The summary table demonstrates that the physical characteristic of each city produces a varying rate of expected interest to cycling. However, not all observations are consistent with the cycling mode share information retrieved from the census of population. Table 22 produces the evidence that Portland contains physical attributes that best suites cyclists and that cycling in Portland is expected to be comfortable and convenient. In fact, the observed mode share of cycling of Portland meets the expectations and the rate in Portland is the highest among the four case study cities. The result from Waterloo also demonstrates the meeting of expectations, where the prevalence of negative attributes to cycling produces a low rate of cycling. However, the expected interest of cycling is not always met with the actual observed cycling mode share. This has been the case for both Madison and Vancouver, where the presence of negatively contributing physical characteristics still reflects a high rate of cycling. Due to the presence of this discrepancy in the expected and observed cycling rates, an examination of policies and plans of action are needed to comprehend the underlaying factors influencing cycling interests.

Chapter 5: Qualitative Results and Discussion

5.1 Introduction

The previous sections of the thesis have established the research goals – to determine the extent to which the case cities have physical attributes that promote or deter cycling. The results from the previous chapter suggest that despite there being some physical attributes in several cities that dissuade cycling use, they have in fact receive strong cycling rate. Although the research assumes that the interest to cycling declines when cities contain physical attributes that dissuade cycling, these discrepancies lead to further questions about the steps the cities have taken to overcome the challenges and successfully influence a greater amount of people to cycle.

In this chapter, I review the planning documents related to active transportation from each case study city. The intention of this review is to determine the level of the cities' awareness of the opportunities and challenges of their physical characteristics. The review of relevant policies also reveals if the case cities have actively sought to solve the weaknesses they experience and to determine if the strategies are successful.

The plans reviewed published in different eras are based on different demands for transport and are informed by local priorities that may have evolved over time. Despite these various dates and foci, the physical characteristics of each city have most likely not changed. As such, there is an expectation that the challenges identified in the previous section will be present and potentially addressed in multiple planning documents. While the timing of each city's plan may not coincide, the goal of the assessment is to determine if, over time, these cities have actively sought to address their shortcomings.

5.2 Policy Analysis

5.2.1 Vancouver, BC:

This research reviewed and compared the following three planning documents published by the City of Vancouver: Vancouver Comprehensive Bicycle Plan (1988), Vancouver Bicycle Plan (1999), and Transportation 2040 (2012). Each of these transportation planning documents outlines the plan of action and may include the local administration's efforts to stimulate interests to cycle. As changing travel habits at a city-wide scale tend to take a prolonged period, observing changes through multiple versions and across the recent decades is necessary to determine the awareness of their barriers to cycling.

5.2.1.1 Comprehensive Bicycle Plan (1988)

The Vancouver Comprehensive Bicycle Plan was the first edition of cycling plans published for Vancouver. The plan outlined goals to encourage cycling use for utilitarian and recreational purpose through engineering, education, enforcement, and encouragement (City of Vancouver, 1988). The plan acknowledged that the city layout is advantageous in popularizing cycling because there is a tightly-knit, local road network, and that the need to support increases in cycling use can be fulfilled by modifying existing streets for cycling safety (City of Vancouver, 1988). In addition, the survey that was released as a part of developing this plan also revealed the popular origins and destinations of cyclists matches the areas discovered by this research to have the highest intersection density (Figure 41). Therefore, the actions outlined in this plan demonstrates Vancouver's awareness of the opportunities of their built environment characteristics in popularizing cycling and has taken advantage of it to prioritize improvements to cycling infrastructure.

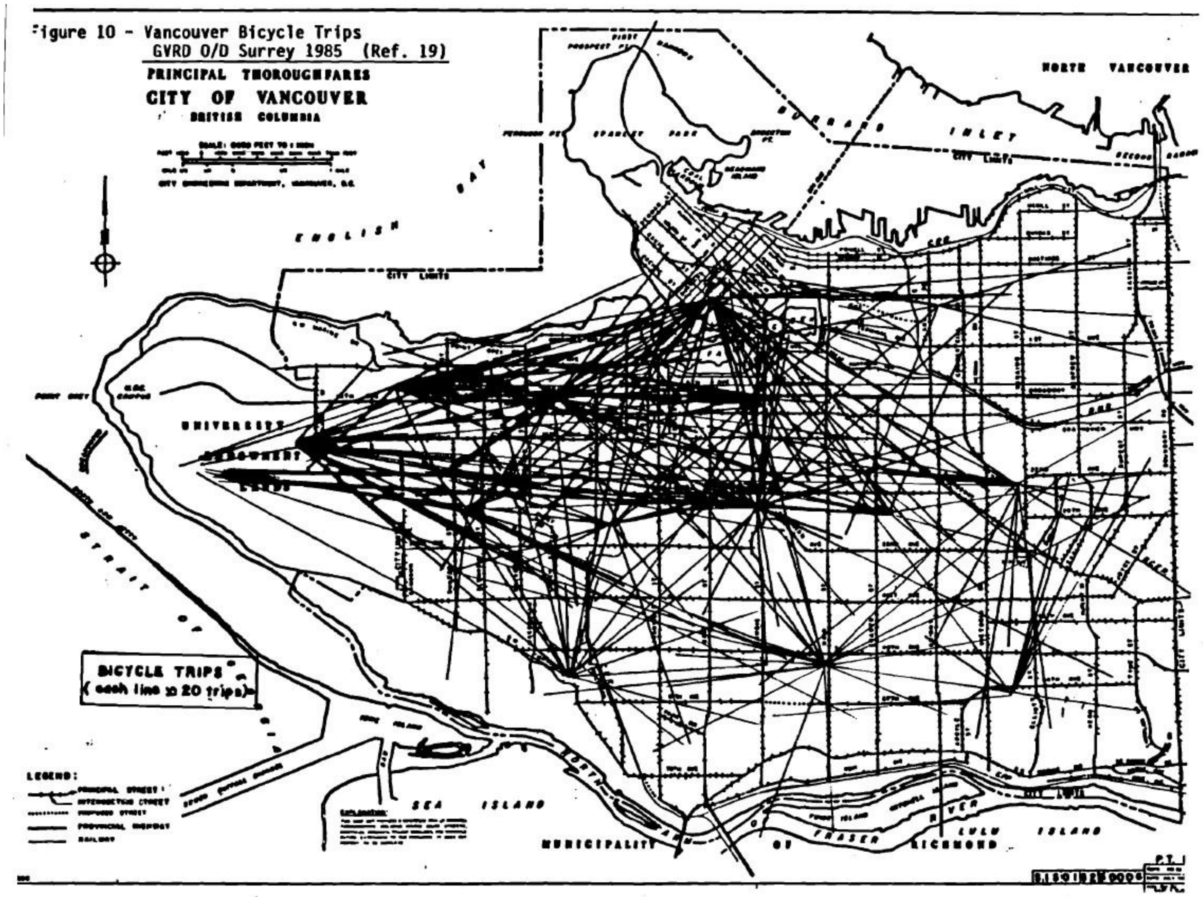


Figure 41 - Bicycle Trip Origins and Destination in Vancouver (City of Vancouver, 1988)

Despite Vancouver having a high proportion of areas with high elevation changes, as discovered in Chapter 4 of this thesis, this plan did not discuss the need to address the challenges for cycling created by the topography. Although the plan discussed the need to improve the comfort of cyclists in the city (City of Vancouver, 1988), the challenges of topography was not included in the consideration of cycling comfort. As a result, Vancouver did not outline specific goals in this plan to revise the network design to overcome the challenges of steep gradient for cyclists who may not have the physical ability to complete the journey.

Chapter 4 of this thesis also revealed that Vancouver's cycling network is not well connected, which may present an obstacle to cycling. In an effort to increase cycling interests, one might expect to see the expansion of the cycling network as a priority in the City's planning efforts. Despite having revealed several places across the city where cycling facility improvements will be placed, however, it did not appear to offer any plan of action to overcome the barrier of network connectivity specifically.

The climate of Vancouver is comfortable for cyclists for most of the year. Cycling in Vancouver is likely made attractive by having mild temperatures in winter seasons and cool summer seasons (Environment and Climate Change Canada, 2021). However, a deterrent to cycling could appear in winter seasons where precipitation is more likely. Climate is discussed in the plan but predominantly with regard to the safety of cyclists in different weather situations (Figure 42). The plan has found that cycling-related fatalities in

Vancouver occur less often in times of high precipitation and low temperature as compared to sunny and warm conditions (City of Vancouver, 1988). Although the analysis shows a counter-intuitive result, it in fact reveal that most cyclists only travel in good weather and more accommodations are needed to support cyclists travelling in different weather conditions.

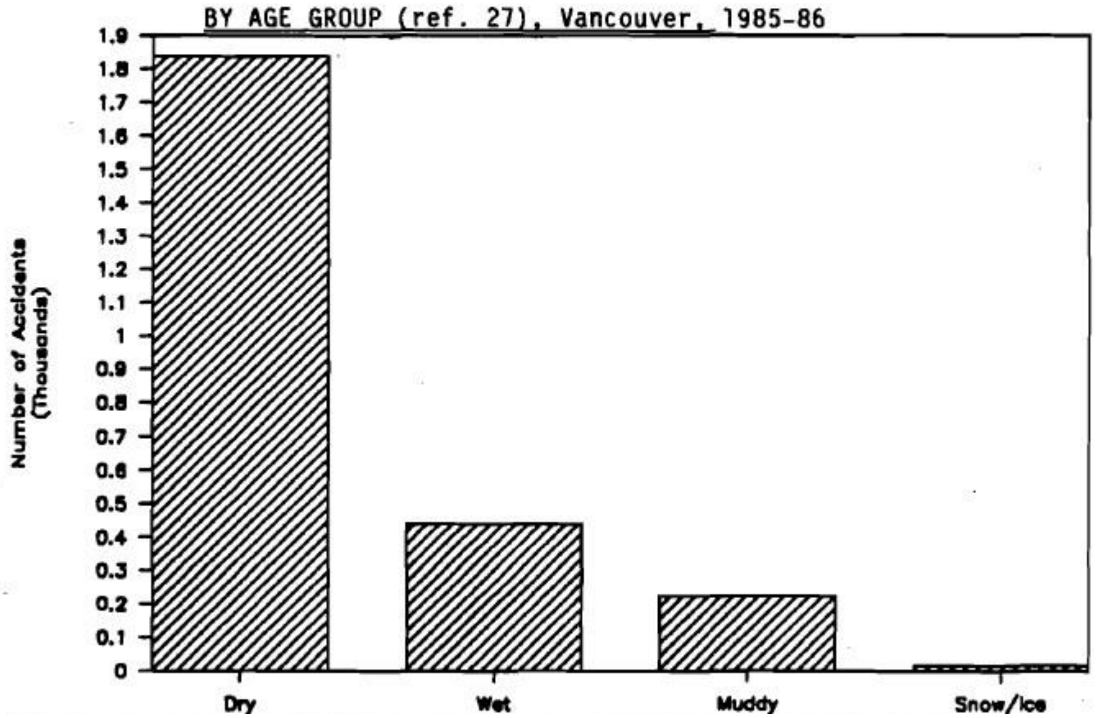


Figure 42 - Reported Bicycle Accidents by Weather Condition (City of Vancouver, 1988)

Another appearance of the discussion on climate throughout the plan in about the changes in perceptions of willingness to cycling in different weather situations. The plan discussed an interesting finding from surveying local cyclists which suggested that in fact 51% of 600 respondents expressed that they are discouraged from cycling because of bad weather (City of Vancouver, 1988). This proves that Vancouver is aware that the people's interest to cycle declines in the undesirable weather, however, with precipitation happening frequently in the city, its has taken few actions to overcome with the challenges.

Chapter 4 of this research discovered that the youth population, between the ages of 15 to 35, contributes to 30% of Vancouver's population, which presents a high potential for cycling to be popularized. One of the approaches listed in the plan to advertise cycling to the youth population is through introducing the option to travel by bike to school-aged children and educating them about cycling safety to stimulate interests at a young age. Another approach listed in the plan was to improve the awareness of cycling and ways to cycle safely in post-secondary institutions and community centres. Therefore, Vancouver has taken some actions to take advantage of this opportunity to further popularize cycling.

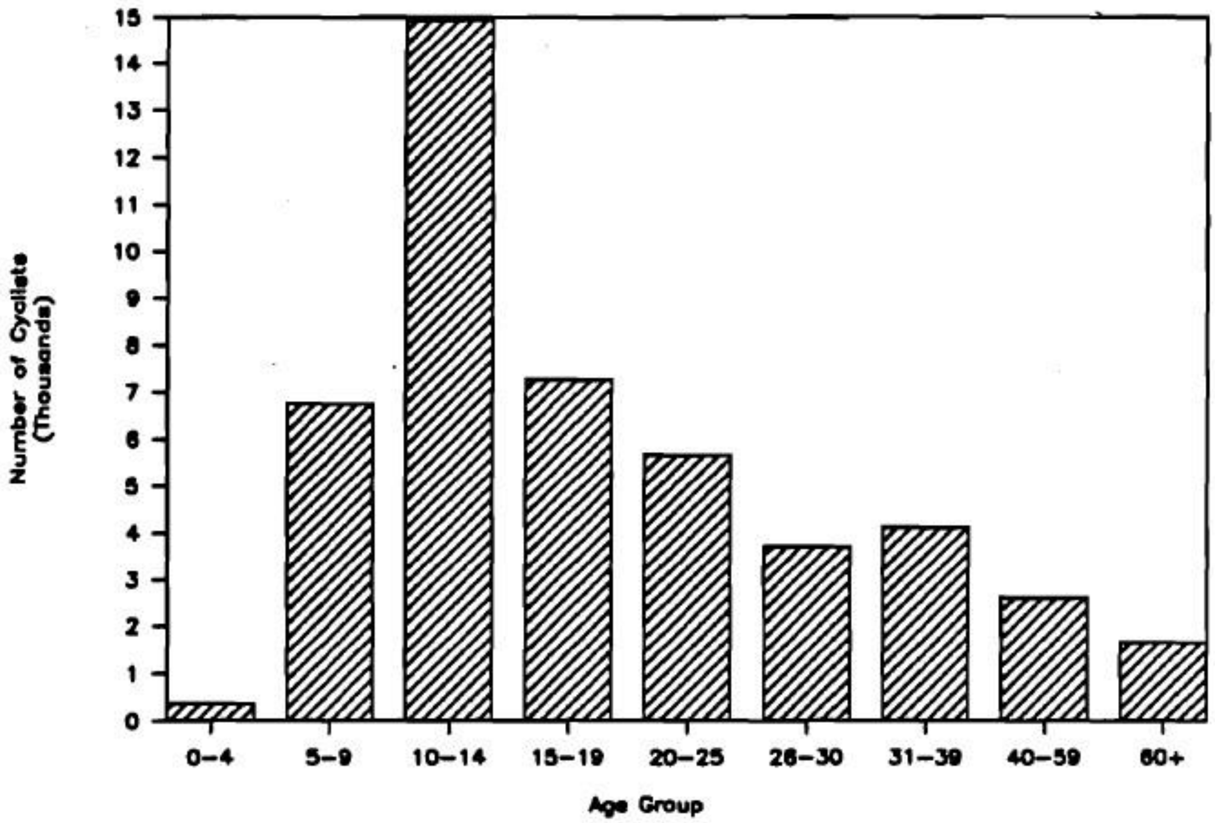


Figure 43 - Age Structure of Cycling Population (City of Vancouver, 1988)

Table 23 – Summary of Strategies – Comprehensive Bicycle Plan (1988)

Attributes	Solutions
Built Environment	• Modify roads to create safe cycling spaces
Climate	• Reduce risk of accidents during precipitation events • Improve cycling comfort by accommodation for cyclists during rain
Demography	• Build awareness of cycling and cycling safety

5.2.1.2 Vancouver Bicycle Plan (1999)

The examination of the subsequent plan, the Vancouver Bicycle Plan published in 1999, also revealed continued action by Vancouver to support growth in cycling usage. In between the 1988 and 1999 publications, Vancouver had renewed its interest in engineering, education, enforcement, and encouragement, to support further growth in cycling rate. The plan outlined further growth in cycling facilities for densely populated areas, such as the downtown core, and growth in suburban areas through traffic calming in residential streets (Figure 44). This then builds upon the goal of the previous plan to support connections to the downtown and efficiently using local streets to expand the bicycle network.

However, this plan has remained the same in terms of addressing the challenges of steep gradients across the city, where there was little to no awareness of the challenges this geographic characteristic could impact the suitability of cycling.

Regarding the connectivity of the cycling network, the plan discussed greater opportunities to expand the cycling network to secondary routes outlined in the previous plan due to increased funding from upper government levels (Figure 44). By having plans to further expand the cycling network, this plan demonstrated that Vancouver has taken some actions to improve connections between the established bike routes and allowing more residents to have approximate access to bicycle path.

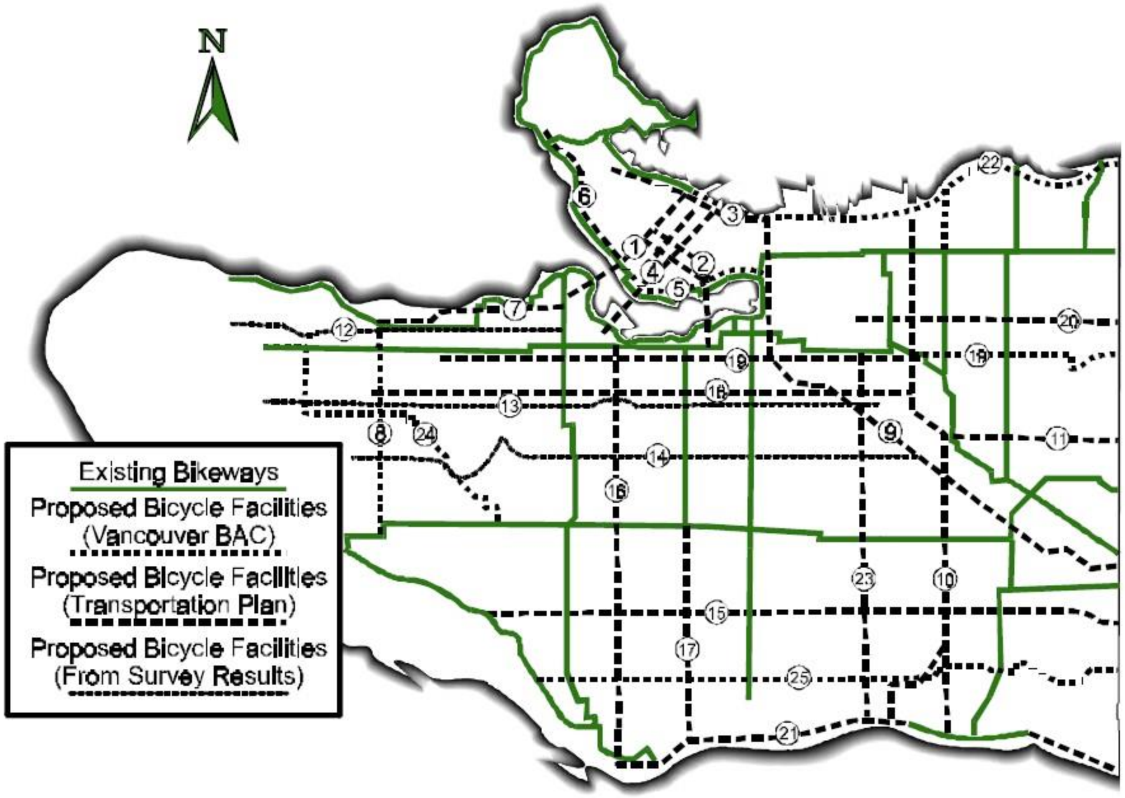


Figure 44 - Proposed Bicycle Facilities (City of Vancouver, 1999)

This plan's discussion of the challenges that Vancouver's climate poses to cycling interest surrounds the acknowledgement of the reduced willingness to cycle in undesirable weather conditions. This plan apparently repeated a version of the previous survey and, in this instance, found that 16% of cyclists have been discouraged from cycling due to bad weather (City of Vancouver, 1999). As a result, despite Vancouver having recognized the impacts of weather on the desirability of cycling, substantive steps have not been discussed in this plan to accommodate for the concerned cyclists. Cities in the similar time of publication has in fact suggested initiatives such as education about winter cycling etiquette, weather-proof bicycle parking, and end-of-trip facilities (e.g., shower and change rooms), to offer more comfort to cyclists traveling in adverse weather (City of Portland, 1996).

Despite having acknowledged that the demography could be a major factor influencing the desirability of cycling as a travel mode, few goals and metrics were set to alleviate the concerns. This plan continues to focus the strategy in promoting cycling through the dissemination of cycling maps and safety tips brochures. Although the promotion campaigns have successfully distributed more than double the amount in the previous version of the cycling map (Figure 45; City of Vancouver, 1999), there were few mentions on the plan to attract youthful riders.

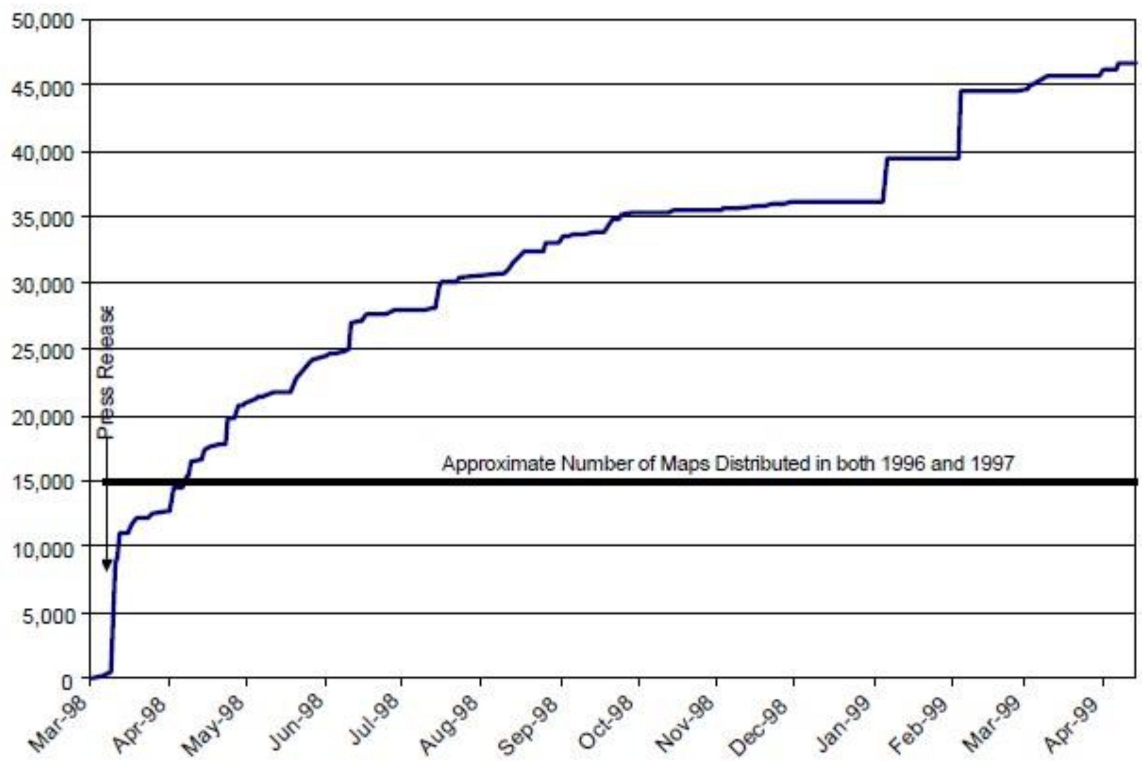


Figure 45 - Quantity of “Cycling in Vancouver” Maps Distributed (City of Vancouver, 1999)

Table 24 – Summary of Strategies – Vancouver Bicycle Plan (1999)

Attributes	Solutions
Built Environment	• Encourage cycling in densely populated areas through traffic calming
Bike Network Connectivity	• Expand cycling infrastructure development to include secondary routes
Demography	• Disseminate cycling maps and safety tips brochures

5.2.1.3 Transportation 2040 (2012)

The Transportation 2040 plan published by the City of Vancouver in 2012 took a different approach from previous versions of transportation and cycling plans. Unlike the previous plans, the Transportation 2040 plan outlined goals addressing a wider range of issues that are indirectly related to transportation, including affordable housing, climate change, and rising fuel prices.

Specifically, in relation to the built environment characteristics, the plan discusses how the relationships between the built environment density and stimulation of sustainable transportation modes should be shaped. This plan has been successfully aware of this challenge; it has outlined substantial steps to encourage urban development to be built to support increased likeliness to use sustainable transportation modes. The built environment improvements have been introduced through initiatives including the facilitation of mixed land uses in transportation corridors to reduce trip distances and making sustainable transportation choices more attractive (City of Vancouver, 2012). Another strategy proposed in the plan was to design the built environment along cycling routes to be welcoming and interesting for cycling to happen (City of Vancouver, 2012). Tools to support this type of built environment include active frontages and people-scaled streetscapes. Therefore, this plan has demonstrated the awareness of built environment as an important geographic issue and has taken substantive steps to address the problem.

The plan has also demonstrated the city's awareness with the problem of topography in the effort to expand cycling. Given that steep slopes are prevalent in the City of Vancouver, having a plan to mitigate this issue is necessary. Although steep slopes are often unavoidable when expanding the bicycle network, the plan outlined strategies to identify routes with steep slopes to allow cyclists to plan for their routes with based on different abilities (City of Vancouver, 2012). The City plan includes providing information to cyclists prior to beginning their trip, such that cyclists can make route choices that match their physical capacities. The strategies presented in the plan demonstrates that Vancouver has significantly changed the approaches from previous versions and have taken substantively more action to address this issue.

Regarding the overall design of Vancouver's bicycle network, the plan emphasized priorities including the construction of a bicycle network to connect with activity centres, direct connections to key destinations and links that facilitate trips to neighbouring municipalities (Figure 46). The plan also outlined specific

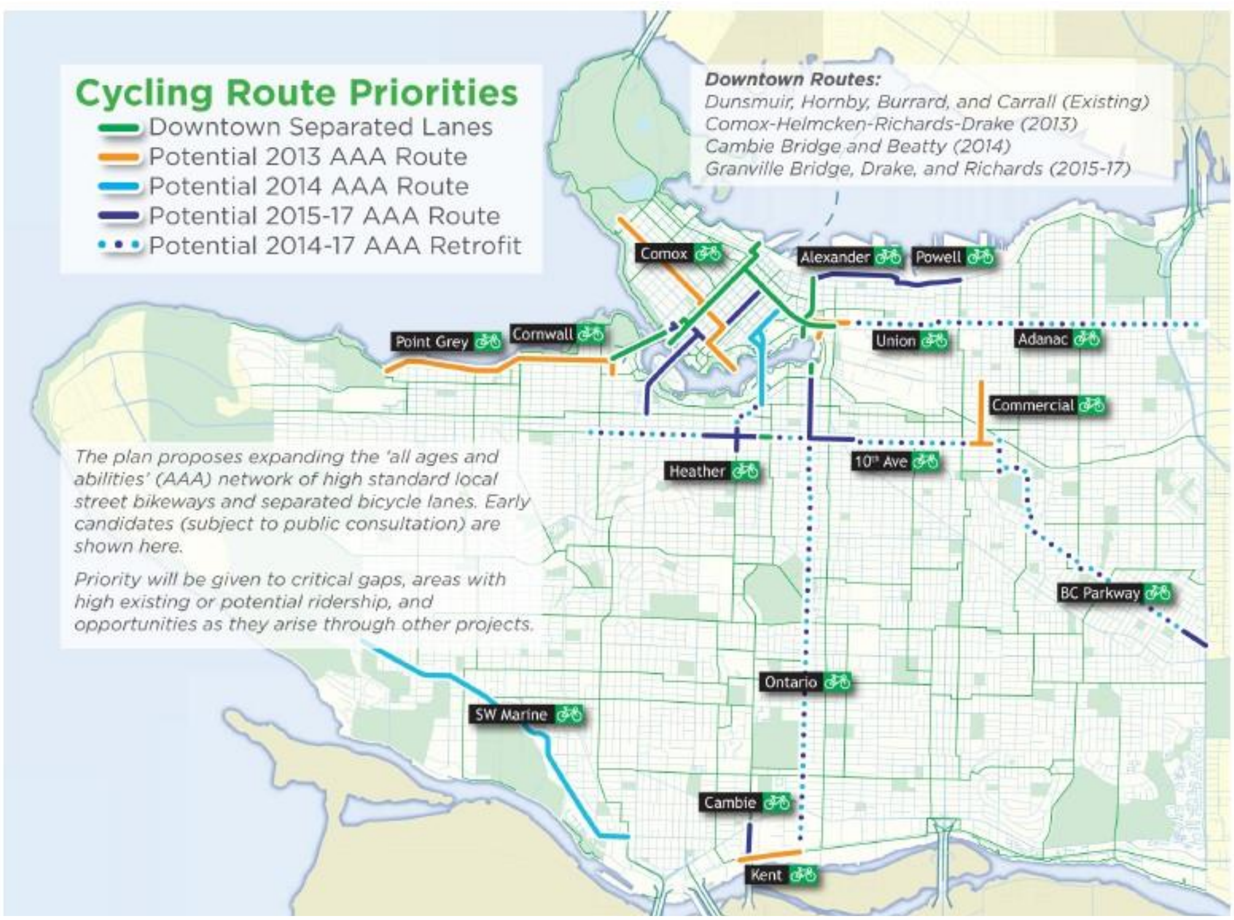


Figure 46 - Cycling Route Priorities (City of Vancouver, 2012)

actions to identify gaps in the cycling network and work to resolve them to maximize the comfort of cyclists (City of Vancouver, 2012). As a result, this plan offered much more specific goals from previous versions to eliminate barriers for cyclists and has demonstrated the willingness to fill in existing gaps in the bicycle network.

This version of Vancouver's transportation plan has outlined substantive steps to accommodate cyclists during times with undesirable weather in the city. Although the city tends to have mild temperature and long periods without rain in the summer, the rainy winter and spring seasons tend to be the main weather-related deterrents for cycling use (Environment and Climate Change Canada, 2021). With the City wishing to expand cycling as a year-round and all-season travel mode, the plan outlined many actions to ensure the needs of different weather are accommodated. One example is to build change rooms and gear storage facilities in locations where cycling activity is high (City of Vancouver, 2012). Another example is to expand weather protection along streets to minimize the weather impact on pedestrians (City of Vancouver, 2012). With these steps outlined, this has certainly demonstrated that the issue surround weather has been made aware and that substantive steps have been taken to accommodate cyclists during uncomfortable weather.

Lastly, in relation to the city's demography, the Transportation 2040 plan demonstrated that Vancouver has realized their strength to promote cycling due to the presence of a large youth population. Although the plan did not specifically discuss strategies to influence youths between the ages of 15 and 35 to cycle, many actions outlined in this plan aim to support the youth population in general to develop a habit of cycling. The steps outlined includes designing bike routes and streets to accommodate all ages and include cycling skills training into school curriculum (City of Vancouver, 2012). In comparison to previous versions, this plan has taken similar steps in emphasizing the need to educate the youth population to develop a cycling culture. While the plan does not emphasize the need to develop bicycle facilities to facilitate trips to post-secondary campuses, the network development plan demonstrates that post-secondary campuses will be supported with the current network plan.

Table 25 – Summary of Strategies – Transportation 2040 (2012)

Attributes	Solutions
Built Environment	• Encourage mixed use developments to create spaces that welcomes cycling activities
Gradient	• Avoid constructing new infrastructure along steep slopes
Bike Network Connectivity	• Prioritize cycling route development to connect key destinations and neighbouring municipalities.
Climate	• Build change rooms and gear storage facilities at destinations with high cycling activities • Expand weather protection along streets to minimize weather impact
Demography	• Design bike routes to accommodate for cyclists in all ages and abilities • Incorporate cycling skills training in school curriculum

5.2.1.4 Vancouver Cycling Plan Summary

The following table summarizes how Vancouver's planning efforts demonstrate awareness of, and have generated solutions for the inherent challenges faced in the City.

Table 26 – Summary of Vancouver Cycling Plans

Account	Comprehensive Bicycle Plan (1988)	Vancouver Bicycle Plan (1999)	Transportation 2040 (2012)
Built Environment	▲	▲	●
Topography	✕	✕	●
Bike Network	▲	▲	●
Climate	■	■	●
Demographics	▲	▲	▲

Legend:

Aware of issue and has taken substantive action: ●

Aware of issue and has taken some action: ▲

Aware of issue and has taken little to no action: ■

No awareness of issue: ✕

5.2.2 Portland, OR:

This research also reviewed and compared the following three bicycle plans published by the City of Portland: Bicycle Master Plan (1996), Portland Bicycle Plan for 2030 (2010), and Portland 2035 Transportation Systems Plan (2020). The plans were reviewed to determine the approach taken by Portland to address the challenges posed by their physical characteristics. As geographic challenges are not always recognized by the decision makers of their city, a review of the current and previous versions of bicycle and transportation plans contributes to understanding whether Portland has proposed adequate strategies to improve cycling infrastructure to address the challenges and opportunities in their physical characteristics. The observation of the evolution between the published plans supporting the development of cycling infrastructure and programs also helps to understand the change in willingness to address Portland's barriers to popularizing cycling by responding to its physical characteristics.

5.2.2.1 Bicycle Master Plan (1996)

The Bicycle Master Plan for the City of Portland was published in 1996 with a concentration on planning for bicycle infrastructure development in Portland. The plan outlined several strategies, including zoning and land use controls, in conjunction with the existing community plans, to ensure that the built environment surrounding future developments support sustainable transportation options. Specifically, the plan discussed the requirement to incorporate a minimum bicycle parking limit in the zoning code for new developments (City of Portland, 1996), and "suggested bicycle improvements [be] incorporated wherever possible" (City of Portland, 1996). This serves as evidence that the decision makers in Portland are aware that the built environment greatly impacts the desirability of cycling and that the City is actively seeking opportunities to improve the built environment for maximum cycling comfort.

Similarly, the topographical constraints in Portland have also received careful attention throughout the plan in the design specifications of proposed bike routes. The plan recognizes that steep terrain and high frequency of elevation changes along bike routes can result in challenges for cyclists who may not have the necessary physical strength to complete their journeys. Because of this, the proposed cycling facilities will be ranked against each other with the magnitude of "topographical constrains, [where] higher score for those projects without terrain that limits potential usage (e.g. steep slopes, limited access)" (City of Portland, 1996). This demonstrates that Portland has been aware of the impacts that high elevation fluctuation has on the desirability of cycling and has created metrics to favour the construction of facilities with lower elevation fluctuation.

Portland's planning of cycling facilities has also involved the strategic placement of bicycle facilities to facilitate improved network connectivity, access to density and minimizing service gaps. The plan has specifically recognized the fact that many of Portland's cycling routes are short and disconnected from other cycling facilities (City of Portland, 1996), which therefore requires the filling of gaps to promote greater utilization. In response to Portland's recognition of this barrier to popularize cycling, the plan discussed the necessity to build a continuous cycling network that "connect areas and sites in as direct a line as possible" (City of Portland, 1996). The strategies described above serves as evidence that Portland has taken some steps to ensure the connectivity of cycling network is maintained.

Portland has also outlined several strategies to accommodate the needs of cyclists who travel under varying weather conditions. One such strategy is the need to build facilities to support cyclists at their destinations to ensure that cycling will become a viable mode of transport throughout the year (City of Portland, 1996). Because it is often difficult to develop fully covered and weather-proof cycling routes throughout the city, emphasis has often been placed on the end-of-trip-facilities such as showers, change rooms, and covered bicycle parking. These amenities are often seen as the ideal to further persuade individuals to cycle year-round (City of Portland, 1996). Because the plan specifically directs "support the provision of bicycle parking, locker, and shower facilities by the private and public sector to aid in achieving the bicycle mode share goal," (City of Portland, 1996) it demonstrates that the City of Portland is aware of and attempting to support cyclists in ideal and poor weather conditions.

With a high youth population in the City of Portland, the plan has also outlined steps to encourage this population group to cycle more often. The plan recognized that the bicycle parking facilities at schools and institutions are often prone to theft and not weather protected, which reduces the desirability of cycling (City of Portland, 1996). Especially when individuals visiting schools and institutions often remain at the destination for more than two hours, unsafe bicycle parking conditions has then become a major deterrent for cycling (City of Portland, 1996). This plan has demonstrated Portland's strong willingness to take advantage of their demographics to expand on the city's already large cycling culture through improvements in bicycle parking condition and introducing education programs in schools. As the "lack of and/or substandard racks and an environment that actively discourages students from cycling to school due to bicycle vandalism and/or theft and traffic problems near schools," (City of Portland, 1996) the plan discussed that more than 200 bicycle parking spaces, at 110 schools, have been added to make cycling more appealing to students (City of Portland, 1996).

5.2.2.2 Portland Bicycle Plan for 2030 (2010)

The Portland Bicycle Plan for 2030 outlined strategies to improve cycling infrastructure for the years between 2010 and 2030. This plan serves as an update to the preceding plan so that the future cycling program development will best reflect the needs of users.

The relationship between the built environment and the desirability of using cycling as a mode of transport has been recognised throughout the document. Chapter 4 of this thesis revealed through an analysis of the city's intersection density that Portland has a concentrated downtown core and large area of low-density suburban environment. For the highest density locations, the plan designates places as bicycle districts, where there is a high concentration of essential destinations and existing or expecting cycling activities (City of Portland, 2010). As a way to grow cycling beyond the urban core, Portland has proposed the integration of cycling with the Portland land-use plan to introduce high-density mixed-use developments along key cycling corridors to improve the desirability to cycling over driving (City of Portland, 2010). The plan also specifically directs the need to "adopt a bicycle transportation policy to create conditions that make bicycling more attractive than driving for trips three miles or less and integrate support for bicycling into other *Transportation System Plan (TSP)* policies" (City of Portland, 2010). Therefore, the plan has demonstrated Portland's awareness of the relationship between land use and cycling use through taking deliberate actions to make cycling more desirable across the city.

The plan has also demonstrated Portland's awareness in the relationship between the city's topography and the desirability of cycling use, particularly when evaluating potential new cycling routes. Portland City staff analyzed communities across the city to determine the areas with a high potential for cycling to be popularized, where the topography was listed as one of the main determinants informing the decision making (City of Portland, 2010). The plan has also outlined that the design of bicycle networks should minimize steep slopes and offer multiple route options for cyclists to avoid steep slopes along their journeys (City of Portland, 2010). The increase of shoulder width "to accommodate safe maneuverability of motor vehicles traveling on steep, winding roads," (City of Portland, 2010) has also been suggested in the plan. The actions mentioned above have demonstrated that Portland has been aware of the relationship between steep slopes and the desirability of cycling and has taken substantive actions to minimize impacts.

Another key factor found to have impact on the desirability of cycling is the connectivity within the cycling network. The 2010 plan considers this connectivity and access to key activity centres across the city. One example was in the bikeway implementation criteria, where questions like "Does the project close a significant gap in the connectivity of the bikeway network" (City of Portland, 2010) to help ensure that new projects are compatible with the existing facilities. Another example was an articulated goal of maximizing the number of residents within a quarter mile of bicycle corridors, and ensuring "that a bikeway be provided every 800 feet in urban areas," (City of Portland, 2010) through the '80 percent' implementation strategy. This strategy is to "focus on spreading available funding widely, so that most Portland residents are close to low-stress bikeways." (City of Portland, 2010) Therefore, this plan demonstrates Portland's awareness of the importance of bicycle network connectivity in making cycling desirable and outlined substantive steps to build on this issue.

With Portland recognizing weather as one of the main concerns for cyclists, the plan outlined strategies to provide weather-protected bicycle parking and establish cycling promotional events in the sunny and warm summer months (City of Portland, 2010). Although Portland does not have many days on average where snowfall happens, the plan specifically discussed the need to "give priority to streets with bicycle facilities when recovering gravel following snow and ice events." (City of Portland, 2010).

Lastly, the plan has also demonstrated Portland's awareness of the relationship between the population demography and the potential of expanding cycling use. The plan demonstrated the importance of this relationship by emphasizing the bicycle education and promotion programs for youths (City of Portland, 2010). The plan emphasized on establishing high quality cycling routes through the Safe Routes to School program, which aims to implement secure long-term bicycle parking spaces, speedbumps, crosswalks, and wayfinding, to improve the desirability of cycling as a transportation option (City of Portland, 2010). The review of this plan revealed that Portland has been aware of the relationship between the presence of a large youth population and the likeliness for cycling to be expanded and has taken substantive steps to address the issue.

Table 27 – Summary of Strategies – Portland Bicycle Plan for 2030 (2010)

Attributes	Solutions
Built Environment	• Introduce high-density mixed-use developments in designated bicycle districts to make cycling more attractive
Gradient	• Increase the width of bike lanes to improve safety between passing vehicles and cyclists
Bike Network Connectivity	• Require new infrastructure to fulfil gap in existing network • Increase the density of cycling facilities to 800 feet
Climate	• Give priority to clearing snow and ice from bicycle facilities
Demography	• Establishing safe routes to school and secure parking spaces

5.2.2.3 Portland 2035 Transportation System Plan (2020)

The Portland 2035 Transportation System Plan outlined the strategies to support the expected growth of Portland in the oncoming 20 years. The planning document for all transportation modes was evaluated for this research because the City of Portland has decided not to update the cycling-specific transportation plan, and decided instead to renew the transportation strategy by considering of all transport modes (Figure 47). This plan does, however, build substantively upon many different transportation plans that were mode-specific, including the bicycle transportation plan published in 2010. The following paragraphs continues to follow the previous structure of presenting the discussion of each key physical characteristic of Portland in the planning document.

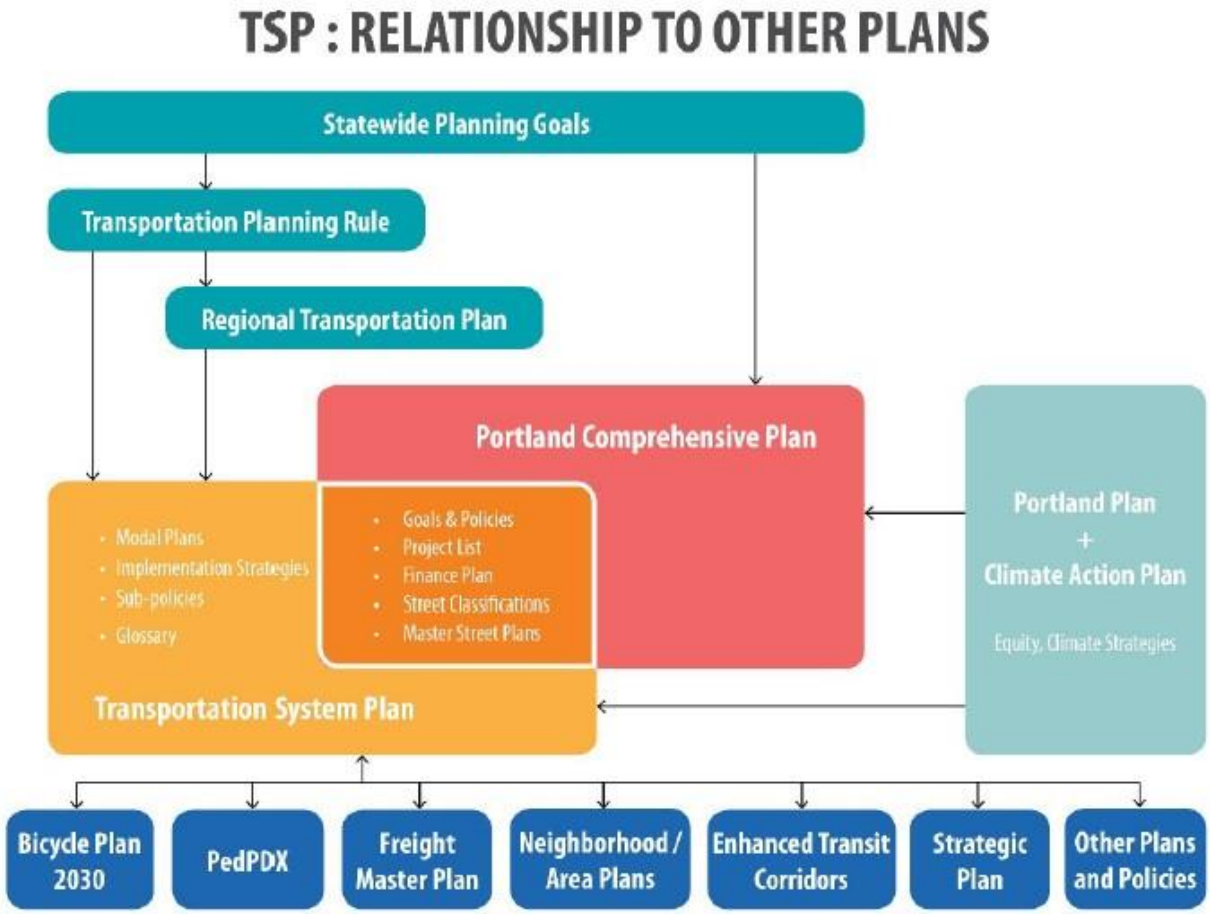


Figure 47 - The relationship between the Transportation Systems Plan (TSP) and other published plans

Strategies to create built environments that support a greater use of cycling are contained in the plan. Since Portland contains a downtown with very high density and surrounded by low density suburban areas, the plan outlined steps to actively evolve the built environment to become more desirable for cycling activities. The plan has also set a goal to focus housing and employment growth in the downtown core and other activity centres across the city to maximize access to transportation facilities and reduce the need of car use (City of Portland, 2020). Portland's consideration of the built environment has also been demonstrated in the design of bicycle facility types, where an increase in density and mixed land uses were often recommended for major bike routes and districts (City of Portland, 2020).

On the other hand, the plan has not outlined many strategies to mitigate the impacts that Portland's topographic form could bring to limit cycling activities. Although the previous plans outlined some steps to ensure that cyclists could make informed decisions on route selection, and designing bicycle facilities to minimize the probability of cyclists to have steep slopes along the cyclists' journey (City of Portland, 2010), this plan has not the progress of mitigating the impacts of topography on cycling activities.

Strategies to fill in the gaps of bicycle networks and to expand the accessibility of Portland's bike network have also been listed throughout this plan. While Portland has a large existing network of bicycle facilities, further improvements in ensuring that the facilities are well-connected, allowing cyclists to access facilities, remains to be done. Urban centres of the city are specifically required to "connect to each other and to other key local and regional destinations, such as schools, parks, and employment areas, by … bicycle sharing, bicycle routes, …" (City of Portland, 2020). Although the plan discussed the need to amend gaps in the bikeway network by adding "new bike lanes and sharrows, improvements to existing bikeways, wayfinding improvements, colored bike boxes and lanes, and signal modifications" (City of Portland, 2020), and allocated funding to deliver the initiatives, the plan did not outline specific metrics to measure their success (City of Portland, 2020).

While previous plans had outlined some strategies to accommodate cyclists travelling in undesirable weather, the current plan did not describe the progress of implementing the previously established initiatives. The plan also did not develop new strategies to provide further accommodations for cyclists or to facilitate other alternatives.

Lastly, the plan also outlined many strategies to influence the youth and student population to cycle. One example is through transportation demand management, where programs, incentives, and activities, are developed to encourage groups of people, such as students, to travel by bike instead of driving (City of Portland, 2020). Another key strategy is to direct new cycling route investments to university campuses (City of Portland, 2020). Additionally, the Safe Routes to School Project that was proposed in the previous plan has been successfully delivered, and is expected to have increased support "for road maintenance and street safety projects over the next four years" (City of Portland, 2020). With the success in the implementation of cycling promotional programs for students and youth, it demonstrates that Portland has taken substantive steps and has successfully influenced more people to cycle.

Table 28 – Summary of Strategies – Portland 2035 Transportation System Plan (2020)

Attributes	Solutions
Built Environment	• Focus development growth on activity centres and connect them with a wide variety of transport modes • Increase density along major bike routes and bicycle districts
Bike Network Connectivity	• Expanding the bicycle network to connect to destinations across the city and region (e.g., schools, parks, employment centres)
Demography	• Direct infrastructure investments to university campuses • Improve the safety of cycling routes connecting to schools

5.2.2.4 Portland Cycling Plan Summary

Table 29 – Portland Cycling Plan Summary

Account	Bicycle Master Plan (1996)	Portland Bicycle Plan for 2030 (2010)	Portland 2035 Transportation System Plan (2020)
Built Environment	▲	●	●
Topography	▲	●	✕
Bike Network	▲	●	▲
Climate	●	▲	✕
Demographics	●	●	●

Legend:

Aware of issue and has taken substantive action: ●

Aware of issue and has taken some action: ▲

Aware of issue and has taken little to no action: ■

No awareness of issue: ✕

5.2.3 Waterloo, ON

The cycling plans from the Region of Waterloo were reviewed to compare the policy responses to address the challenges and opportunities identified in Chapter 4. Waterloo, Ontario and Madison, Wisconsin allow for an evaluation of two municipalities in North America with large student populations.

This research specifically reviews the Region of Waterloo Cycling Master Plan (2004) and the Region of Waterloo Active Transportation Master Plan (2014). This review offers insight about the awareness of the regional and local governments in the Waterloo Region in addressing key physical characteristics that influences cycling.

5.2.3.1 Region of Waterloo Cycling Master Plan (2004)

In 2004, the Region of Waterloo published a Cycling Master Plan that outlined a variety of strategies to establish a rationale for growth in cycling facilities and promote cycling to Waterloo residents. The plans authors presented the drafts of the work and sought input from residents during the development of this plan through an internet webpage, presentations, and focus group sessions.

The relationship between the built environment through which bike routes are designed and built and the desirability of cycling was recognized throughout the document. This relationship was evident in the cycling plan, where plans to "shift direction in community design and provide mixed use, livable cities [that] includes a shift in road design, … [and] providing sufficient space for cyclists on the road" (Region of Waterloo, 2004). Similarly, the plan also conveys the Region's intentions to increase the density of bicycle facilities to "respond to population density… [where] the density of routes in urban areas will be greater than that in rural areas" (Region of Waterloo, 2004).

The plan implies that Waterloo decision makers are aware of the relationship that exists between topography and the propensity to cycle. One element contained in the planning document is a requirement to accommodate cyclists with different physical abilities to create "a good cycling environment [that] encourages individuals to make a personal commitment to developing their skills in a gradual manner" (Region of Waterloo, 2004). The plan also recognized that only a experienced cyclists are comfortable to take on the challenges steep hills present, and that topography is an important consideration in the design of bicycle facilities to maximize comfort (Region of Waterloo, 2004). As some parts of the Waterloo's cycling network contains steep slopes, more accommodations are needed to offer alternative routes for those who are less physically able to travel on a milder slope.

Bicycle network connectivity and density have also been discussed frequently throughout the plan. The Waterloo plan acknowledges that cyclists often cannot traverse the gaps in the cycling network, due to equipment limitations and safety concerns which, in turn, negatively affects the desirability of cycling (Region of Waterloo, 2004). To address this shortcoming, the plan proposes that Waterloo's cycling network achieve greater interconnectivity "[providing] connectivity across major barriers (Provincial Highways, Rail Lines, Grand River, etc.)" (Region of Waterloo, 2004). Another key aspect of the plan is to design bicycle facilities that "provides access to major utilitarian and recreational destinations in the region, … by way of the Regional and/or Local Municipal networks, with adequate and appropriate connections," (Region of Waterloo, 2004) to make cycling a more appealing option for most trips.

As heavy snowfall and low temperatures are common for winter seasons in Waterloo, the plan has taken some steps to maintain bike corridors to ensure that cycling remains to be a viable travel option in winter (Region of Waterloo, 2004). The plan contains a set of winter operation guidelines to remove snow on key cycling routes to ensure the safety of cyclists, and on-street pathways will be cleared along with the regular snow removal on roadways (Region of Waterloo, 2004). Moreover, the Waterloo plan calls for the provision of covered bicycle parking to allow cyclists to store their equipment securely (Region of Waterloo, 2004). Recognizing the integration between transit and winter cycling, the Waterloo plan includes support for subsidizing transit passes for cyclists to use transit during winter months in replacement of travelling by bike (Region of Waterloo, 2004). With the steps mentioned above taken by Waterloo, it has demonstrated that the city is aware of the impacts and has taken substantive steps to minimize impact of cycling desirability.

On the topic of demography, Waterloo's plan calls for the introduction of cycling ambassadors whose responsibilities will include encouraging youths and students to cycle (Region of Waterloo, 2004). The presence of ambassadors offer an opportunity to share personal experiences of cycling which will help people understand the convenience of cycling, and form a reminder about the option of cycling (Region of Waterloo, 2004). The ambassadors can also support cyclists with safety tips and responsible cycling habits.

Table 30 – Summary of Strategies – Region of Waterloo Cycling Master Plan (2004)

Attributes	Solutions
Built Environment	• "shift direction in community design and provide mixed use, livable cities [that] includes a shift in road design, … [and] providing sufficient space for cyclists on the road" (Region of Waterloo, 2004).
Gradient	• Accommodate cyclists in all ages and abilities by avoiding steep slopes along new cycling routes
Bike Network Connectivity	• The density of bike lanes should be proportional to the built density • Provide cycling connectivity across major obstacles (e.g., highways, railroads, and waterways) • "provides access to major utilitarian and recreational destinations in the region" (Region of Waterloo, 2004)
Climate	• Clear snow and ice from on-street bike routes at the same time on roads for motorized traffic. • Construct covered bicycle parking spaces for cyclists
Demography	• Encourage youth and students to cycling through cycling ambassadors

5.2.3.2 Region of Waterloo Active Transportation Master Plan (2014)

The Region of Waterloo Active Transportation Master Plan established the direction for the Region of Waterloo to make cycling and walking more comfortable for residents. The plan was established in consultation of more than 360 people who attended staff-led meetings and events, and the involvement of key stakeholders and advocacy groups (Region of Waterloo, 2014).

This plan continues to emphasize the development of the cycling network through the evaluation of potential demand in the specified corridor, with land use density being one of the key indicators (Region of Waterloo, 2014). For example, the demand for cycling is high in mixed-use and high-density areas because common destinations are a short bike ride away. Similarly, the plan contains strategies proposed to mitigate the impact of topography. Reflecting the learnings from a survey of residents who expressed that steep slopes are a main barrier to cycling (Region of Waterloo, 2014), the plan includes the installation of "steep grade ahead" signs (as seen on many roads for motor vehicles) for cyclists, and designing bike routes in areas with less steep slopes (Region of Waterloo, 2014). Therefore, Waterloo has improved from the previous version to be more attentive to the cyclists' concerns and taken more actions to minimize the impact.

Recall that Chapter 4 of this evaluated Waterloo's cycling network and identified deficiencies in its connectivity. This plan recognized this issue and outlined some steps to solve the problem. The plan includes a strategy to analyze the existing network, identify gaps, and develop a list of places requiring a fix (Region of Waterloo, 2014). Interestingly, in some corridors, there is an expectation that demand for facilities may be approaching capacity and without space to reconfigure traffic lanes (Region of Waterloo, 2014). In these cases, the plan calls for future demand to be quantified in cycling corridors and, where necessary, develop "parallel routes to major arterial roadways by essentially encouraging [action from] Area Municipalities" (Region of Waterloo, 2014).

The strategies outlining steps to accommodate for cyclists in different weather conditions have also been listed on this plan. Since poor weather conditions could have great impact on the desirability of cycling, the plan recognized that actions needed to be taken to allow cyclists to travel safely during difficult weather. With Waterloo often experience low temperatures and heavy snowfall during winter and high temperatures during summer (Environment and Climate Change Canada, 2021), appropriate measures to improve cyclists' experience will be necessary. Specifically for winter weather, the plan outlined suggested "that operators begin clearing this network within 6 hours of significant snowfall (note this includes some trails)" (Region of Waterloo, 2014), and "[work] with the Area Municipalities to determine what enhanced winter maintenance practices are most appropriate for the network sections" (Region of Waterloo, 2014). Therefore, the plan demonstrates that Waterloo is aware of the impact that unpleasant weather could have on the desirability of cycling and has taken some steps to ensure that the option of cycling remains accessible in all weather patterns.

Lastly, the plan has also outlined some strategies to support the travel demand of the large post-secondary student population in the Waterloo Region. The plan has demonstrated that Waterloo recognized the strong potentiality for students and youth to cycle because they tend to have the physical ability to cycle (Region of Waterloo, 2014). With a high proportion of the city's population being enrolled into post-secondary institutions and within the age group of 15-35 years old, Waterloo has taken advantage of their demographic opportunities to develop cycling facilities for this population to further encourage them to cycle. Examples include maintaining bike routes to post-secondary campuses during winter and designing facilities that suits all ages and abilities (Region of Waterloo, 2014). Therefore, the plan demonstrates that Waterloo has been aware of the opportunities in their demographics and has taken some steps to develop this opportunity.

Table 31 -Summary of Strategies – Region of Waterloo Active Transportation Master Plan (2014)

Attributes	Solutions
Built Environment	• Using the developments around potential cycling routes to evaluate demand for their use. This measure will help cycling routes to be constructed in highly developed places and stimulate greater interests to cycling.
Gradient	• Install "Steep Grade Ahead" signs to alert cyclists • Design bike routes in areas with gentle or no slopes
Bike Network Connectivity	• Plan for future demand by constructing cycling routes along neighbouring streets of existing cycling corridors.

Climate	• "that operators begin clearing this network within 6 hours of significant snowfall (note this includes some trails)" (Region of Waterloo, 2014) • "[work] with the Area Municipalities to determine what enhanced winter maintenance practices are most appropriate for the network sections" (Region of Waterloo, 2014)
Demography	• Regular maintenance on cycling routes connecting post-secondary campuses • Designing bicycle routes that accommodates cyclists with all ages and abilities

5.2.3.3 Area municipal active transportation and cycling plans (2020/2021)

As the local government structure for the Region of Waterloo consists of an upper-tier regional government, and many area municipalities, they each manage a different service to support residents under their jurisdiction. Since transportation is a shared responsibility, and each level of government have been placed in control of different facilities, plans are created by each municipality to support active transportation programs within their jurisdiction. Although the Region of Waterloo contains of seven area municipalities, this research will only be reviewing the plans from the City of Waterloo, Kitchener, and Cambridge, because nearly all of Waterloo's cycling facilities are contained in them and they are much more populous in comparison to the remaining municipalities. This research will therefore be reviewing the City of Cambridge Bike Your City Cycling Master Plan (2020), the City of Kitchener Cycling and Trails Master Plan (2020), and the City of Waterloo Transportation Master Plan Update 2020 (2021), specifically, to understand whether the cities have taken different approaches than their regional government to develop the physical and demographic characteristics to make cycling an appealing mode of transport.

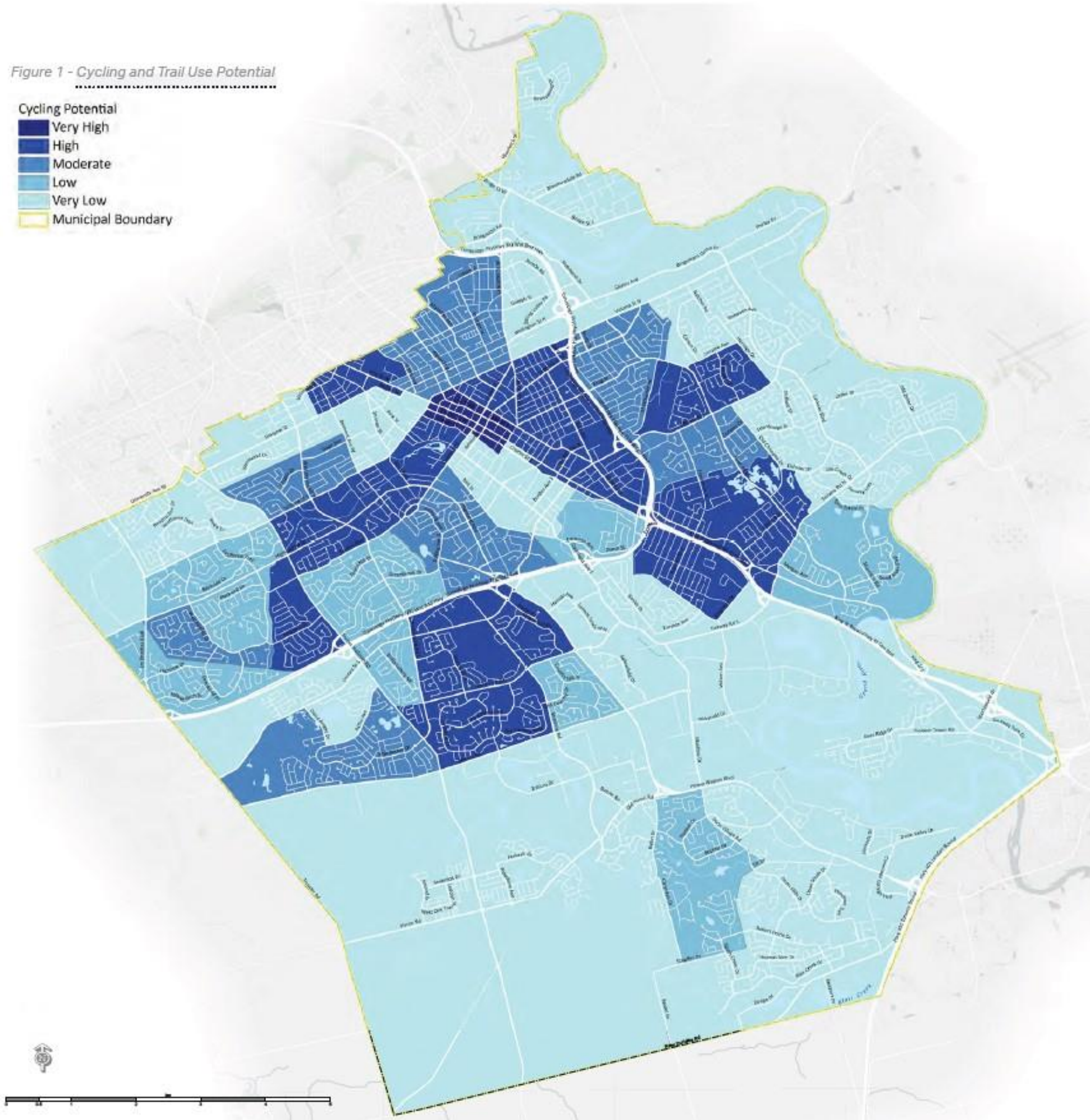


Figure 48 - Cycling and Trail Use Potential (City of Kitchener, 2020)

The recognition of the built environment's impact on the desirability of cycling has been consistent in all cycling plans published by the area municipalities. The built environment is an important topic for consideration because this research has found that the communities across the Waterloo Region contains mostly of low density buildings, which makes cycling less desirable. Because of this, the plans published by Cambridge, Kitchener, and Waterloo, have all emphasized on the need to incorporate land use in the decision for the locations and the design of new facilities in consistent with the region-wide initiative (City of Cambridge, 2020; City of Kitchener, 2020; City of Waterloo, 2021). Evidence from the progress of implementing this initiative shows that Kitchener has gradually introduced more urbanized areas that creates a potential for cycling use (Figure 48). The success in increasing the density of common destinations and activities is also evident in the City of Waterloo (Figure 49), as the closer proximity to each other will likely improve interests to travel by bike.

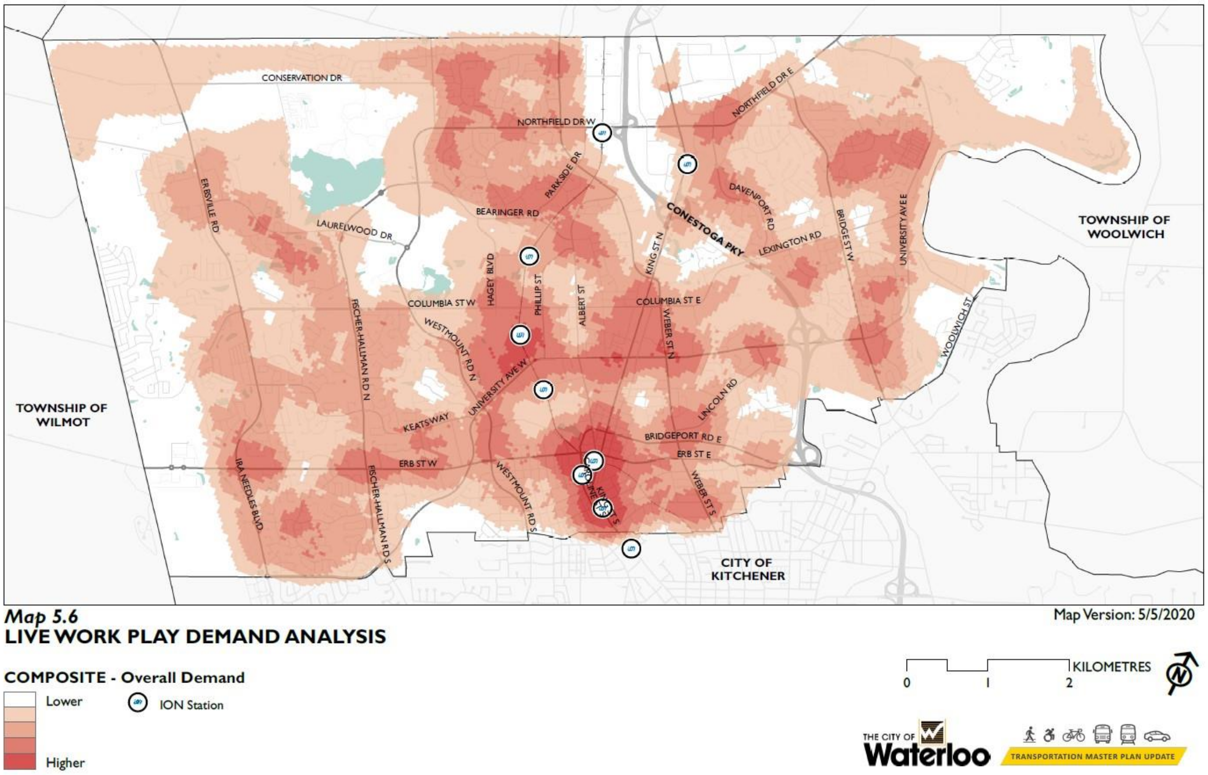


Figure 49 - Live Work Play Demand Analysis (City of Waterloo, 2021)

The plans published by the area municipalities in Waterloo have also demonstrated their understanding of the impact that challenging topography could have on the desirability of cycling. With 6% of survey respondents in the City of Kitchener expressing a concern about challenging topography, it is evident that this is an issue that needs to be addressed (Figure 50; City of Kitchener, 2020) The cycling plans from area municipalities have considered different technology and infrastructure design to ensure that individuals in all ages and abilities could cycle utilize the facilities (City of Cambridge, 2020; City of Kitchener, 2020; City of Waterloo, 2021). In addition, the plan also suggested to include warnings for steep slopes along cycling corridors to advise cyclists of the possible challenges (City of Cambridge, 2020; City of Kitchener, 2020; City of Waterloo, 2021).

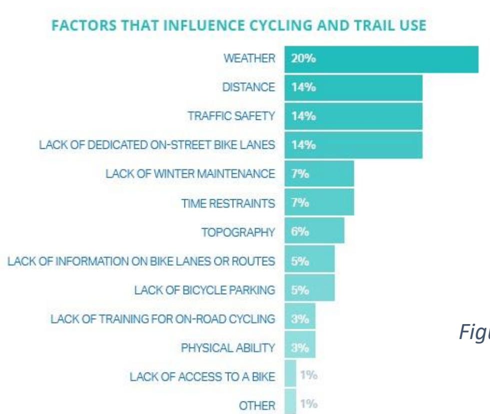


Figure 50 - Factors that Influence Cycling and Trail Use (City of Kitchener, 2020)

The area municipalities in Waterloo have also recognized the importance of having a well-connected and continuous network of bicycle facilities to help people cycle more often. The bike network's connectivity is important to be considered because this research has found that many of the facilities only supports access to a small proportion of the city. Each of the three area municipalities have then emphasized on filling the gaps within cycling facilities to "ensure continuity of facilities to the extent possible, including providing consistent facility types along an entire corridor where possible" (City of Cambridge, 2020). The plans by each of the three area municipalities have also emphasized on integrating the "existing regional cycling and trail infrastructure to ensure connectivity across jurisdictions" (City of Kitchener, 2020). This therefore demonstrates that all three municipalities have recognized the importance of building a well-connected bicycle network in the attempt to popularize cycling and have taken substantive steps to solve the issue.

The impact of weather on the desirability of cycling has also been recognized throughout the plans that are published by Cambridge, Kitchener, and Waterloo. As it is common for the Region of Waterloo to experience heavy snowfall and low temperatures during its long winter season, the result from a survey of cyclists by the City of Kitchener has shown that 20% of respondent are concerned about cycling in winter (Figure 50; City of Kitchener, 2020). Because of this, the plans from each area municipality have outlined strategies to best maintain key cycling corridors during winter seasons, which includes "providing weather protected bicycle parking" (City of Kitchener, 2020) and "giving streets with bicycle facilities a higher snow clearing priority" (City of Kitchener, 2020). In addition, the City of Cambridge (2020) has suggested to implement educational programs about winter cycling to help cyclists build a habit of cycling year-round. From this, it is evident that all three area municipalities have been able to recognize the impact that weather has on the desirability of cycling and have taken substantive steps to overcome the challenges.

The impact on the desirability of cycling, induced by presence of a youth and student population, has also been recognized throughout the plans published by Cambridge, Kitchener, and Waterloo. Strategies that target specifically on the youth and student population has been discussed throughout the plan because the Region of Waterloo is home to several post-secondary institutions and youths who are often more interested to cycle for transport (Winters et al., 2010). The plans from all three municipalities also have policies to promote cycling to youths in the city and design facilities in support trips to and from post-secondary institutions that are in addition to the regional government's strategy (City of Cambridge, 2020; City of Kitchener, 2020; City of Waterloo, 2021). The emphasis to bring the cycling network closer to academic institutions is greater in the City of Waterloo because of the presence of several university campuses (Figure 51).

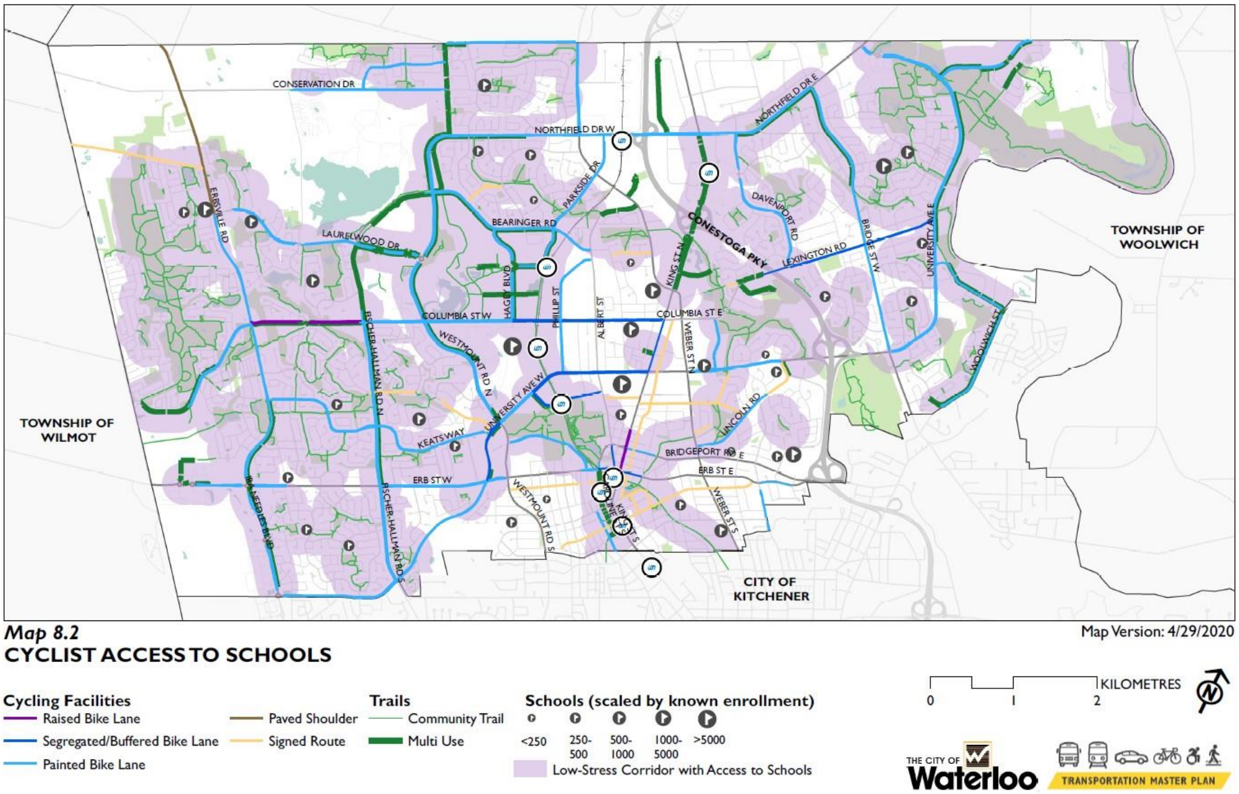


Figure 51 - Cyclist Access to Schools (City of Waterloo, 2021)

Table 32 – Summary of Strategies – Area municipal active transportation and cycling plans (2020/2021)

Attributes	Solutions
Built Environment	• Increase density around activity centres across the region to encourage cycling use.
Gradient	• Include warning sings ahead of routes with steep grades • Explore the use of new technologies and design approach to minimize impacts on steep grades
Bike Network Connectivity	• Ensure the consistency of the infrastructure type and continuity of cycling routes in future facility developments
Climate	• Provide weather protected bicycle parking • Prioritize clearing snow and ice from bicycle routes • Establish education campaigns (e.g., go by bike week in winter, and lessons on winter cycling)
Demography	• Designate new cycling facilities to university campuses

5.2.3.4 Waterloo Cycling Plan Summary

Table 33 – Waterloo Cycling Plan Summary

Account	Region of Waterloo Cycling Master Plan (2004)	Region of Waterloo Active Transportation Master Plan (2014)	Area municipal active transportation and cycling plans (2020/2021)
Built Environment	▲	▲	●
Topography	■	▲	▲
Bike Network	●	●	●
Climate	▲	▲	●
Demographics	■	▲	▲

Legend:

Aware of issue and has taken substantive action: ●

Aware of issue and has taken some action: ▲

Aware of issue and has taken little to no action: ■

No awareness of issue: ✕

5.2.4 Madison, WI

The policies supporting the development of bicycle programs at Madison, WI were compared to understand the evolution of approaches to improve cycling. This research will be reviewing the Bicycle Transportation Plan for the Madison Urban Area and Dane County, Wisconsin published in the year 2000 and 2015 to determine the policy development progress of the City of Madison to overcome the challenges posed by its physical characteristics.

5.2.4.1 Bicycle Transportation Plan for the Madison Urban Area and Dane County (2000)

The Bicycle Transportation Plan has been developed to support the continued development of Madison's bicycle program through the approaches of engineering, education, encouragement, and enforcement.

The strategies to create a built environment suitable for cycling at Madison were discussed throughout the plan. Madison's recognition of the relationship between cycling use and the built environment has been evident in the plan through establishing the premise that "If land use practices and the street network result in long distances between origins and destinations, bicycling is less practical" (City of Madison, 2000). Because of this, the plan outlines strategies to design a built environment that support cycling activities. Examples include the creation of an "an interconnected street system, which provides bicyclists with direct routes and alternatives to travel along high-volume roadways," (Figure 52; City of Madison, 2000) and designing "compact, mixed-use development, which provides destinations within easy bicycling of people's homes and workplaces" (City of Madison, 2000).

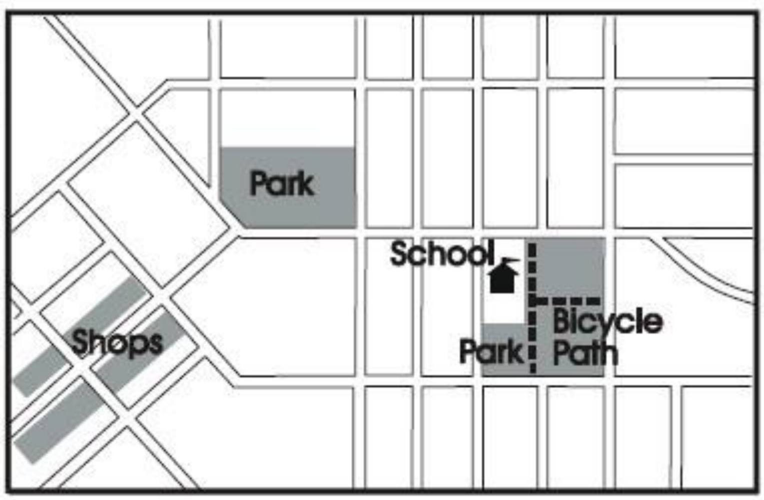


Figure 52 - Example of an interconnected street system (City of Madison, 2000)

The relationship between the city's topography and the comfort of cycling has also been demonstrated throughout the plan. Madison recognition that steep slopes often create undesirable environments for cyclists has been evident throughout the document (City of Madison, 2000). One of which is demonstrated through suggesting that "grades on shared-use paths should be kept to a minimum, especially on long inclines" (City of Madison, 2000). As Madison is a city containing high elevation changes, this suggestion offers a greater amount of space to pedestrians and cyclists to maneuver alongside each other. Another evidence of the recognition of topographic challenges is in the suggestion that "the width of bicycle paths should be increased on steep slopes, where feasible" (City of Madison, 2000).

The understanding of the relationship between the connectivity of bicycle network and the desirability of cycling as a transport mode for Portland residents has also been demonstrated throughout the plan. As this research has found gaps in Madison's bicycle network that impacted its connectivity, the plan demonstrates Madison's willingness to address the issue through a few strategies. One of which is to establish a vision of an interconnected bike network and take action "to ensure a seamless inter-connected bicycle transportation network across jurisdictional boundaries and at different functional levels of roadway systems" (City of Madison, 2000). Another is suggestion to develop a "continuous bicycle way systems within cities and villages in the county, with connections to the countywide bicycle way system" (City of Madison, 2000). On top of that, the plan outlined strategies to optimize the on and off-street facilities to improve continuity of the bicycle network (City of Madison, 2000). However, the role of the shared-use paths [is] not be used to preclude on-street bicycle facilities, but rather to complement the on-street bicycle facility network" (City of Madison, 2000).

Madison's acknowledgement of weather as a factor that influences the desirability of cycling has also been evident throughout this planning document. This research found Madison's climate tends to have low temperatures and high rates of snowfall during their long winter seasons, which makes cycling difficult to be used for most of the year. Because of this, Madison has demonstrated their recognition of the importance of winter maintenance on bicycle facilities throughout the plan to improve the desirability of cycling. One of which is to design the roadway to prevent the accumulation of water which makes ice easy to be formed during winter seasons (City of Madison, 2000). On top of that, Madison also proposes to design bike lanes to not be separated with parked cars to simplify snow removal operations (City of Madison, 2000). However, the plan falls short of discussing a firm timeline for snow removal operations. On the idea of end-of-trip facilities, the plan also discussed the need for weather-protected bicycle parking spaces to alleviate concerns surrounding cycling in unpleasant weather (City of Madison, 2000). Therefore, this plan demonstrates Madison's recognition of the impacts that weather could have on the desirability of cycling and has taken some steps to mitigate the issue.

Lastly, Madison's recognition that cycling could be further popularized through having a large youth and student population within the community has also been demonstrated throughout this plan. With Madison having a large student and youth population, due to the presence of a popular post-secondary institution within the city, the plan outlined many steps to present cycling as a viable option for them. One of which is to design bicycle facilities to serve the students' travel needs and ensuring their safety during the cycling journey (City of Madison, 2000). Another strategy proposed in the plan is to integrate the network of cycling routes within post secondary campuses to the city-wide routes (City of Madison, 2000). The middle and high school students have also been included in the scope of the plan through outlining steps to educate them with safe cycling habits and establishing promotional programs (City of Madison, 2000). Therefore, this plan demonstrates that Madison has been aware of the high potential for cycling to be expanded for their large youth and student population and has taken some steps to help make cycling a convenient travel mode for them.

Table 34 – Summary of Strategies – Bicycle Transportation Plan for the Madison Urban Area and Dane County (2000)

Attributes	Solutions
Built Environment	• Design streets that are interconnected and synchronize land use planning to create direct cycling routes
Gradient	• Minimize slopes on on-street shared bicycle pathways

	• Widen bike paths along shared segments of roads with steep grades
Bike Network Connectivity	• Offer seamless connections within the network to neighbouring municipalities • Optimize on and off street bike facilities to improve continuity
Climate	• Design roads and bike paths to avoid the accumulation of water, which will turn into snow and ice during winter • Simplify snow removal through removing parking and other barriers between motorized traffic and cyclists • Construct weather protected bicycle parking facilities
Demography	• Designate new cycling facilities to university campuses and support the students' needs • Integrate cycling routes within campuses to the city-wide network • Establish cycling safety education programs for students

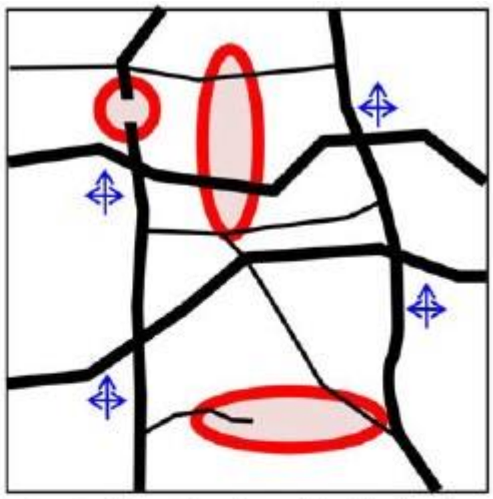
5.2.4.2 Bicycle Transportation Plan for the Madison Metropolitan Area and Dane County (2015)

This version of the Bicycle Transportation Plan for Madison, published in 2015, serves as an update from the previous version and sets a new direction for the development of bicycle facilities in Madison. At the time of publish, Dane County, where Madison is located in, already has over 500 miles of multi-use pathways and many more on-street facilities to support cyclists to travel safely round the city. While the previous version aims to promote cycling for utilitarian purposes to reduce the dependency of personal private vehicles, this plan will instead focus on overall cycling as a transportation option.

The relationship between the built environment and the suitability of cycling has continued to be recognized throughout the plan. With the Chapter 4 of this research having found that Madison consists mostly of suburban neighbourhoods and low-density urban centres, the plan outlined strategies to improve the built environment to make cycling more convenient and attractive. One of which is to "support and strengthen local land use policies for compact, mixed-use development in appropriate areas, and for designing and constructing bicycle facilities in new development projects" (City of Madison, 2015). Another approach is to design facilities with the considerations of land use and street design to become more welcoming to cyclists by "adopting and implementing complete streets goals, laws, and policies" (City of Madison, 2015). Therefore, this plan demonstrates that Madison continues to recognize the importance of creating a soothing built environment in encouraging more people to cycle and has taken some steps to make cycling successful.

Madison has also continued the recognition of the impact that topography could have on the desirability of cycling throughout this latest version of the bicycle plan. As the Chapter 4 this research has found Madison to have high elevation changes throughout the city, it would be important for this plan to address the possible impacts of steep slopes to ensure that more people are drawn to cycling. The concerns about the impact that steep slopes bring to the desirability of cycling has been evident within the design of bikeways (City of Madison, 2015). For example, the primary bikeways are recommended to avoid steep slopes to maximize access to riders in all ages and abilities. In addition, the plan also proposes to "expand online mapping efforts to make it easier to find information on bicycle routes that include information such as the location of steep hills" (City of Madison, 2015). The plan therefore demonstrates that Madison has been aware that its topography poses to be a major barrier to promoting cycling and that substantive steps are taking place to mitigate the impact.

The value of having a continuous and highly dense bicycle network has also been recognized by Madison as demonstrated throughout this current version of the bicycle plan. As this research discovered that Madison's bike network presents many gaps, and contains a low density of cycling facilities, it will be important for the plan to outline steps to maintain continuity in the bike network. The review of this plan reveals Madison's awareness of this issue through having recognized the issue of disconnected networks, and has established the Bicycle Function Classification System to identify the locations of concern (Figure 53; City of Madison, 2015). In addition, the plan has also emphasized on maintaining a high density of bicycle facilities to allow residents to access them within a short distance. During the time of publication, the plan indicated that 47% of Dane County residents live within a quarter mile away from a high-quality bicycle facility (City of Madison, 2015). As the time progresses, Madison aims to allow more residents to have access to bicycle facilities by decreasing the spacing of facilities to 1-0.5 miles for primary bikeways and 0.25-0.5 miles for secondary bikeways (City of Madison, 2015). Therefore, this plan reaffirms Madison's recognition of problems surrounding the existing bike network and will be taking substantive steps to address them.



3. Gaps in the network are identified and improvements are prioritized; wayfinding is added

Figure 53 - The Bicycle Functional Classification System (City of Madison, 2015)

Madison has also demonstrated the recognition that weather is an important factor that influences the decision to cycle in this version of the bicycle transportation plan. The plan outlined the results from a recent survey by the University of Wisconsin discussing the changes in travel mode decisions between

Mode Split Summary for the University of Wisconsin - Madison

Group:	Students		Faculty/Staff		UW Hospital	
Weather:	Good	Bad	Good	Bad	Good	Bad
Bike	22.1%	3.4%	17.4%	3.7%	5.2%	0.6%
Walk	49.4%	32.0%	4.2%	2.4%	1.8%	1.7%
Transit	18.6%	53.1%	14.7%	25.0%	12.5%	12.7%
Auto/Carpool/Other	9.9%	11.5%	63.7%	68.9%	80.5%	84.9%

Figure 54 - Mode Split Summary for the University of Wisconsin (City of Madison, 2015)

good and bad weather, where the amount of people choosing to cycling in bad weather is significantly lower than in good weather (Figure 54; City of Madison, 2015). Because of this, the plan discussed the need for weather-protected bicycle parking facilities to allow cyclists to store their vehicles securely (City of Madison, 2015). The plan has also discussed the need for maintaining bicycle facilities year-round by "clearing snow, ice, and debris from bike lanes and shared-use paths in a timely and reliable manner" (City of Madison, 2015) to ensure that cycling could still be a viable option for most people despite unpleasant weather conditions. On top of that, the plan emphasized on educating the public about cycling safety during winter, and hosting bike to work days in winter, to help residents discover the possibilities of winter cycling and develop travel habits (City of Madison, 2015). Therefore, the plan can serve as evidence that weather has been recognized by Madison as a major barrier to cycling and that substantive steps has been taken to address this problem.

The identification of Madison's large youth and student populations as an opportunity to popularize cycling has also been evident throughout this version of the plan. With this research finding that Madison containing a large proportion of youth residents, there could be a high opportunity to encourage them to cycle. The plan has outlined steps to promote cycling to the youth and student population through education, engagement, and facility design (City of Madison, 2015). One of which is to expand the existing bicycle education program to a greater amount of residents and helping the disadvantaged to own bicycles and learn how to safely ride them (City of Madison, 2015). In addition, the plan has also discussed the necessity to design cycling facilities to support the needs of the student population and removing barriers preventing them from cycling by creating a points system that allow students to "earn points based on encouragement and awareness-raising activities, and top schools receive cash prizes" (City of Madison, 2015). Therefore, this plan has demonstrated Madison's recognition of opportunities within their demographics and has taken substantive steps to help youths to travel by bike more often.

Table 35 – Bicycle Transportation Plan for the Madison Metropolitan Area and Dane County (2015)

Attributes	Solutions
Built Environment	• "support and strengthen local land use policies for compact, mixed-use development in appropriate areas, and for designing and constructing bicycle facilities in new development projects" (City of Madison, 2015) • "Adopting and implementing complete streets goals, laws, and policies"
Gradient	• Minimize slopes on on-street shared bicycle pathways • Provide online maps to help cyclists plan their route ahead of time and select routes based on their ability and confidence
Bike Network Connectivity	• Establish the Bicycle Function Classification System to locate gaps in the cycling network. • Reduce spacing between cycling facilities to 1-0.5 miles to improve access
Climate	• Design roads and bike paths to avoid the accumulation of water, which will turn into snow and ice during winter • Clear snow, ice, and debris from cycling facilities in a timely and reliable manner • Construct weather protected bicycle parking facilities
Demography	• Assist residents to own or rent bicycles easily

	• Expand cycling safety education programs for students • Allow schools to compete for prizes by having more students cycle

5.2.4.3 Madison Cycling Plan Summary

Table 36 – Madison Cycling Plan Summary

Account	Bicycle Transportation Plan (2000)	Bicycle Transportation Plan (2015)
Built Environment	●	▲
Topography	●	●
Bike Network	●	●
Climate	▲	●
Demographics	▲	●

Legend:

Aware of issue and has taken substantive action: ●

Aware of issue and has taken some action: ▲

Aware of issue and has taken little to no action: ■

No awareness of issue: ✕

5.3 Summary of Results:

The following table lists the results from both the quantitative analysis and the qualitative policy analysis.

Table 37 – Summary of Results

Account	Vancouver, BC		Portland, OR		Waterloo, ON		Madison, WI	
	Quant.	Policy	Quant.	Policy	Quant.	Policy	Quant.	Policy
Built Environment	●	●	▲	●	×	▲	×	●
Topography	▲	▲	●	▲	●	▲	▲	●
Bike Network	▲	▲	●	▲	×	●	▲	●
Climate	▲	●	●	▲	▲	●	▲	▲
Demographics	▲	▲	▲	●	●	▲	●	●
Expected Cycling Interests	Medium		High		Low		Low	
Recent Cycling Mode Share	6.1%		6.4%		1.2%		5.3%	

Legend:

Supportive for Cycling: ●

Supports Cycling Partially: ▲

Not Supportive for Cycling: ×

Chapter 4 concluded that differences often exist between the expected desirability of cycling, informed by the cities' performance in physical characteristics that are conducive to cycling, and the observed cycling rate for commuting purposes. Because of the existence of this discrepancy, it was then necessary to examine the policy approaches to overcome the challenges. The results from Table 37 demonstrates that effective application of policy initiatives and robustness of strategies will positively contribute to cycling activities. A good example of which is the City of Madison, where they have observed a high cycling rate after offering robust strategies to accommodate for the cyclists' needs. Similarly, Portland recognized the opportunities and challenges of their city and tailored their solutions to their challenges. However, the cases of Vancouver and Waterloo show very different results between the expected and observed rate of cycling. In Waterloo's case, the quantitative results demonstrate that Waterloo's physical attributes do not support cycling activities. Although the policy responses are mostly tailored to overcome the physical challenges in Waterloo, they have failed to attract new cyclists. Vancouver's case presents another problem where their physical characteristics and policy responses partially support cycling activities, but they can stimulate greater interest to cycle as demonstrated in their mode share.

Chapter 6: Conclusions

6.1 Summary of Findings

The purpose of this research is to determine the attributes that influence the interests to cycle, form assumptions about the rate of cycling based on the presence and absence of the attributes, and examine the ability for planning to solve the challenges in making cycling appeal to the residents of a city. In the case of this research, two pairs of cities (Vancouver, BC and Portland, OR; Waterloo, ON and Madison, WI) were used to correlate the cities' attributes and each city's cycling rate for commuting activities, as well as examine the robustness of their planning policies to mitigate the challenges. The examination of this topic is important for the planning field at this time because many North American cities are increasingly interested in improving the design of urban spaces to accommodate cyclists (Pucher & Buehler, 2021). However, cycling may not be suitable for all cities if their physical and demographic characteristics cause inconvenience to cyclists. Planning solutions must be established as a result to mitigate the barriers to cycling. Therefore, the decision-makers within local authorities can take the results of this research to inform the necessary areas of improvement and determine how they compare with similar cities.

The following section outlines the key findings of the research and their implications in response to the research questions.

The Geographic and Demographic Factors that Influences the Suitability of Cycling

This research reveals several physical characteristics and demographic attributes affect the likelihood of cycling being popularized in a particular city. The attributes include the built environment, topography, bicycle network connectivity and density, climate, and demographics. These attributes can produce positive and negative impacts towards the experiences cycling in a city. As an example, one would expect that a city with moderate climate, low precipitation, relatively flat topography, with a high density of quality cycling facilities will generate more cycling activities than a similarly sized city with more extreme climate and topography, or less well-developed cycling infrastructure.

Since many North American cities were planned and developed at the height of personal motorized vehicle's popularity and, as a result, communities were designed for their use (Newman et al., 2016). Because in auto-centric cities the distances between the common origins and destinations tend to be greater in low density and suburban areas, cycling is often less advantageous for travel as compared to driving (Moudon et al., 2005). Whereas, high-density urban development tends to produce short distances between the common destinations, which makes cycling more advantageous compared with driving (Moudon et al., 2005). As a result of the travel distances presented by different built environment of cities, interests to cycle declines if cycling requires significantly more time and physical effort than driving.

Another physical attribute that was found to have an influence on the suitability of cycling is the topography of the city. As places with high elevation changes tend to require a greater amount of physical effort to traverse the slopes, individuals who do not possess the or do not wish to exert the physical capacity, will be deterred from travelling by bike. The problem is exacerbated when cyclists need to appear professionally at their destinations, and the physical challenges in cycling can result in personal appearances that are inconsistent with professional settings. The slower traveling speed and longer travel time that result from traversing grades were found to have an impact on the willingness of individuals to cycling for their trips (Rodríguez & Joo, 2004). The negative impacts of steep slopes on the suitability to cycle has also been found through the responses in the surveys of cyclists conducted by previous research works (Li et al., 2012; Winters et al., 2011).

The connectivity of bicycle networks is also another physical characteristic that influences the suitability of cycling in a city. Key features of an ideal cycling network, as described by Furth (2021), include separation from other road users as well as safe and direct connections between common origins and destinations. Another quality of a good cycling network includes a high density of facilities. Because a high density of cycling facilities reduces the distance that cyclists are required to travel to access the cycling facility, researchers like Buehler & Dill (2016) have all agreed that a high density of facilities positively correlates to the willingness to cycle.

However, parts of bicycle networks in many cities may have been constructed at different times and gaps may exist within the network. When these gaps include segments that are poorly designed or incompatible with cycling, the entire route is often perceived as difficult and unsafe. With safety being one of the top concerns for people to cycle, the presence or absence of safe facilities to cycle on will have an impact on the decision to cycle (Sallis et al., 2013). The difficulties in travelling on the cycling routes, and the detours cyclists may face, also limit the appeal of cycling because cycling often competes with driving in the context of most North American cities.

The climate of a city can also influence individuals' interest in cycling. Previous literature suggests that temperatures between 5 and 25 degrees Celsius are considered most suitable for cyclists (Böcker & Thorsson, 2014). Similarly, cities with low precipitation rates are likely to create more opportunities for cycling (Böcker & Thorsson, 2014). Conversely, cities having long periods of the year outside of this ideal climate could make cycling less desirable (Pucher et al., 2021). In the context of North American cities, during the long winter seasons, frigid temperatures are seen as a major deterrent for people's decision to cycle (Spencer et al., 2013). Meanwhile, the research by Motoaki & Daziano (2015) also demonstrated the decline in cycling interests during days where rain and snow events occur. However, the days with snow events deter cyclists more than rain because cycling routes are not often maintained, making cycling more challenging (Motoaki & Daziano, 2015). Because cycling is a mode of transport that is highly susceptible to the weather conditions, whereas private automobile is not for most cases, cities experiencing poor weather conditions may have significant negative impact on the interests to cycle.

The interests in cycling could also be influenced by the demographic attributes of a city. Because the population between the ages of 15-35 tends to be the age group that cycles most actively (Pucher & Buehler, 2021; Winters et al., 2010), the presence or absence of this population group can become an indicator of whether the city is suitable for cycling to become popularized. The presence or absence of post-secondary students can also play a role in the overall interest in cycling because students tend to cycle for their trips more often (Chaney et al., 2014).

The Presence or Absence of Attributes in the Case Study Cities

The observation of whether the attributes are present or absent in the case study cities is largely determined through evaluating the quantitative representation of the attributes. The built environment was evaluated through the analysis of the density of street intersections due to the observation that the built density is positively correlated with the density of street intersections. The topography was represented by the percentage of total area containing a steep slope and the percentage of bicycle routes containing a steep slope. The bike network completeness was assessed through an analysis of the connectivity and density of bicycle networks. The climate was measured through climate averages obtained from meteorological agencies and amount of time in a city that falls within the ideal range for cycling. The demographics were analyzed by evaluating the proportion of population that are youth and enrolled into post-secondary institutions. The results from the case study cities are listed as follows and they mostly align with the assumption that the attributes have an impact on the rate of cycling.

The review of the attributes revealed that the physical and demographic characteristics of Vancouver are mixed in terms of their impact on cycling activities in the city. One of the attributes that hinders interests to cycling is the topography. Although Vancouver as a whole contains a high variation of topography, local planners have wisely invested in bike routes on gentle slopes, reducing the potential hinderance to user comfort. The climate of Vancouver has also been found to be a barrier to cycling due to the frequency and intensity of rain that occurs in the fall and winter seasons. However, the warm winter and cool summer temperatures in Vancouver are conducive to cycling trips. Another attribute that has the potential to positively impact the cycling rate in Vancouver is the built environment; many areas in the city contain high intersection density. Vancouver is also home to a large youth population and post-secondary students, again resulting in the potential for growth in cycling in the city.

In Portland, the review of the attributes revealed that the physical and demographic characteristics has are generally positive, leading to an expectation of high levels of cycling activities in the city. Portland has high intersection density, and similarly a high built density. As a result, cycling trips throughout the city will likely be short for most cyclists. Portland's urbanized areas tend to support cycling through having gentle slopes throughout the city and on bicycle paths. The highly connectedness and density of Portland's bicycle network also helps cyclists to access the facilities conveniently. The climate of Portland – with mild temperature ranges and low precipitation throughout the year – is strongly supportive of cycling. The youth and post-secondary student population in Portland has also contributed to the achievement of high cycling rate.

In contrast to Portland, the review of Waterloo's attributes revealed that the physical and demographic characteristics create barriers to cycling in the region. Due to the low-density built environment in most of the region, cycling trips tend be long for most cyclists travelling across the city. Fortunately, the region and its bike paths are generally flat, allowing for relatively low effort cycling between origins and destinations. While the Region of Waterloo has been investing in cycling facilities and has achieved a high density, Waterloo's network remains disconnected, with unfortunate gaps creating poor overall connectivity. Because Waterloo tends to have winters that are long with heavy snow, cycling interests remain low for extended periods during the year. The strongest attribute observed in Waterloo is the large youth and post-secondary student population.

Like Waterloo, Madison's built environment consists mostly of suburban and low-density neighborhoods, which lead to longer average trip length and declined cycling interest. The topography of Madison is a major barrier for cyclists in the city due to the high elevation changes along bike routes and throughout the city. Madison's has a cycling network that is well connected, but modest in its spatial extent, with limited access to many parts of the city. The long winters with frequent snowfalls also impacted the cycling desirability due to the extra effort afforded on cyclists. As Madison is also a town with large youth and post-secondary students, there is also an opportunity for cycling growth.

The Impacts of Planning in Case Study Cities

The review of the cities' attributes described above presents a picture of cities with inherent advantages and disadvantages in terms of generating cycling activities. The data on actual cycling rates suggest that some of the case study cities are performing at or above expectations, while others are not. One possible explanation for these disparities in performance can be the extent to which planning processes have meaningfully capitalized on positive attributes and purposefully addressed negative attributes. Based on this observation, a comparison was conducted of cycling (or active transportation) planning policies published by the case study cities. The longitudinal comparison between the planning policies of a city informs whether they have actively addressed their challenges in promoting cycling. The city-by-city comparison between the policies published by similar sized cities informs the robustness of their policies in acting on their challenges. The results were compared against the latest observed mode share for commuting purposes and the results of the quantitative attributes to determine if their planning policies supported the interests to cycling.

The review of Vancouver's planning policies has demonstrated that the city has partially supported expanded interests in cycling. Vancouver's ideal built environment for cyclists was developed through having outlined robust strategies in supporting urban intensification throughout the city in multiple versions of planning policies. However, Vancouver's planning failed to address the issues surrounding the topography and the connectivity of bicycle networks. Fortunately, the impacts of the city's climate on cycling desirability have been recognized in the plans. Especially at the latest version of the transportation plan, the planners offered strategies (e.g., shower rooms and lockers) to accommodate cyclists travelling during adverse weather at common destinations. Although Vancouver has a large youth population, and post-secondary students, the plans did not outline substantive steps to make cycling more convenient for this specific group.

Portland's planning policies include efforts to create a built environment that promotes cycling. In addition, Portland's plans have also outlined some steps to offer greater options for cyclists who may become challenged to traverse steep slopes throughout the city. The connectivity and density of cycling facilities in Portland have also been addressed throughout the different versions of the planning document to ensure maximum comfort for cyclists. However, the plan lacks any discussion of strategies to accommodate cyclists during adverse weather. With Portland having a large youth and post-secondary student population, the plans have also discussed extensive strategies to appeal to this group and make cycling a convenient travel mode for them.

As noted earlier, Waterloo benefits from few steep areas that hinder cycling. As a result, regionally planning does not focus on addressing grades, but some plans have briefly described some strategies to warn cyclists of steep slopes ahead. Curiously, many planning documents have articulated a vision for a well-connected and dense network of cycling facilities, but these networks remain disjointed. With Waterloo often experiencing very cold winters with frequent snowfall, the plans outlined extensive steps to accommodate cyclists during adverse weather by setting a timeframe for snow plowing and prioritizing the maintenance of major cycling routes. Although Waterloo has a large post-secondary student population, the plans have not outlined substantive steps to make cycling an appealing option for them.

One of the primary concerns identified in Madison was topography, including the presence of many steep grades. Through its planning processes, Madison has addressed the issue by developing cycling facilities in areas more suitable for cyclists of all skill levels. Madison has also outlined substantive steps to create a well-connected network of on- and off-street paths to maximize cycling comfort. However, discussions on how to address the challenges posed by Madison's climate remain absent. The demographic opportunities to promote cycling are evident in planning documents; strategies include suggestions to expand infrastructure to connect to post-secondary institutions and educating students about cycling safety at a young age.

6.2 Recommendations

The following are recommendations for local authorities to consider as they work towards popularizing cycling in their cities:

- As the physical and demographic characteristics of cities do not always support cycling activities, it is important to determine if natural barriers exist and form appropriate policy actions to overcome the challenges. Madison, Wisconsin, as a part of the research, are great examples to prove the importance of policy actions in overcoming natural barriers to cycling. As most quantitative attributes for Madison do not offer comfort for cyclists, the decisive actions taken by decision makers to accommodate cyclists' needs have in fact generated observed cycling rates that exceed expectations.
- However, even when a city's quantitative attributes are found to be conducive to cycling interests, robust policy actions are still required to seize the opportunity and influence more people to cycle. The evidence from Portland motivates this recommendation. Although Portland's physical characteristics have mostly contributed to cycling activities, decision makers continued to direct support to planning policies that are favourable to cyclists, resulting in the strongest overall cycling among the cities studied.
- The research discovered that the cities in the United States of America have been more successful in developing planning policy responses to overcome barriers to cycling. Although Vancouver was able to stimulate a high cycling mode share, I believe that the popularization of cycling can be even more successful if their policy responses are more focused on addressing their barriers. Similarly, the planning actions in the Region of Waterloo can also be strengthened when more coordinated efforts exist between the lower tier area municipalities and the upper tier regional government. While the lack of coordination will often lead to disjointed cycling facilities, strengthening the coordination effort will create a consistent set of cycling facilities that will attract new and current cyclists to cycle more frequently.
- Introducing incentives for people to adopt new micro-mobility technology in recent years, such as e-bikes and e-scooters, may improve the comfort of traversing steep slopes when using active travel modes.

6.3 Limitations of Study

The limitations regarding the quantitative research methods are as follows:

- The focus of this research work is to examine the physical geography of cities that influences the interest to cycling, rather than identifying the elements of social geography such as the cycling culture.
- Inaccuracies may occur in the intersection density analysis because cities are regularly developing and despite best efforts, the data sources used in this research may not reflect current conditions.

- The bicycle network connectivity analysis method may not accurately represent all possible ways the cyclists could travel between two points in a city. The definition of a cycling facility differs between jurisdictions meaning the assessment – which attempted to connect origins to destinations using bicycle infrastructure of a given category – may not always have been able to find paths of similarly quality.
- The research also may not accurately compare the full extent of each case study city's topography due to the difference in the resolution of data sources. The topographic data used to represent the Canadian cities have a resolution of one square metre, whereas the topography of American cities have a resolution of ten square metres.
- The multiple accounts evaluation model used for this research was designed to compare two pairs of cities that are similar in their physical and demographic characteristics. Applying the same methods for city pairs containing substantially different physical and demographic characteristics creates challenges of scale, potentially influencing the interoperability of the results.
- The cycling mode share statistics used in this research represents the percentage of people who travels by bicycles for commuting purposes in each city, and does not capture the proportion of population who rides their bikes for non commuting trips.

6.4 Further Research

Future research work on the possibility of increasing cycling in cities challenged by their physical characteristics will certainly improve the results from this study. For future research, there may be value in extending the methods used here. Of particular interest would be the application of this approach in other contexts, specifically cities with substantively different cycling mode shares. For example, the comparison between North American and European cities can inform the difference in planning approaches to stimulate a culture to cycle for transport.

Another way to extend this research model is to consider and extended or different set of attribute assumptions. This study has only used five attributes (built environment, topography, bicycle network connectivity, climate, and demographics); more extensive research with greater resources could discover a greater amount of attributes that can influence cycling use and gain a different result.

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