

Impact of Riparian Landscape Patterns on Water Quality in an Urbanizing River  
Basin: A Case of Cedar River - Lake Washington Watershed

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**Abstract**

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The increasing concern about the deteriorating water quality in rivers and streams in urban areas has led to a focus on protecting natural riparian land covers along these water bodies. The conversion of these land covers, such as forests and wetlands, to urban and agricultural land puts pressure on riparian ecosystems and their ability to perform important ecological functions, including maintain water quality. This thesis explores the Cedar river-Lake Washington watershed, with the intent of identifying the spatial and temporal relationships between riparian landscape patterns and selected physical and chemical parameters, thereby allowing the prediction of water quality trends. The analysis shows that there is a link between the spatial and temporal patterns of the riparian landscape within 100m and 300m buffer width and a few physical and chemical parameters of water quality. Specifically, there is a significant relationship between the composition and configuration of the riparian landscape and Total Nitrogen and

Nitrate-nitrite concentrations. No significant relationship was found for other tested parameters. The findings indicate the need to consider the riparian landscape patterns at multiple scales in defining strategies to protect water quality.

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# TABLE OF CONTENTS

List of Maps .....	v
List of Figures .....	vi
List of Tables .....	vii
1 Introduction.....	1
1.1 Problem Identification .....	3
1.2 Study Rationale.....	6
1.3 Research Questions.....	7
1.4 Thesis Outline .....	7
1.5 Limitations of the Study.....	8
2 Conceptual Framework.....	9
3 Literature Review.....	11
3.1 Riparian Landscape.....	11
3.1.1 Riparian Landscape Patterns and its Functions .....	12
3.1.2 Factors influencing Riparian Landscape Functions.....	14
3.1.3 Delineation of Riparian Landscape and its Significance .....	20
3.1.4 Status of Riparian Areas .....	21
3.2 Water Quality.....	22
3.2.1 Water Quality Standards.....	23
3.2.2 Washington State Standards and Guidelines for Water Quality.....	24

3.3	Historic Changes in LULC and River and Stream Water Quality in the Study Area	
	Watershed .....	25
3.3.1	LULC Changes .....	25
3.3.2	Changes in Water Quality .....	27
4	Research Methodology .....	29
4.1	Study Area Overview .....	29
4.1.1	Geographical Context .....	29
4.1.2	Demographic Conditions .....	31
4.1.3	Land Use .....	31
4.2	Research Methods .....	32
4.3	Data Collection .....	33
4.3.1	Sources of Land Cover Data .....	33
4.3.2	Sources of Water Quality Data .....	37
4.3.3	Data Dictionary .....	38
4.4	Data Processing .....	38
4.4.1	Delineation of Riparian Buffers .....	38
4.4.2	Processing Water Quality Data .....	39
4.5	Data Analysis .....	39
4.5.1	Trend Analysis .....	40
4.5.2	Correlation Analysis .....	42
4.5.3	Regression Analysis .....	43
5	Results .....	46

5.1	Trends in Riparian Landscape Patterns.....	46
5.2	Trends in Water Quality.....	51
5.3	Correlation between Riparian Landscape Patterns and Water Quality Parameters.....	52
5.4	Significance of Riparian Landscape in Predicting Water Quality .....	54
6	Discussion.....	63
7	Conclusion .....	65
	Bibliography .....	67
	Appendix A.....	76
	Appendix B.....	87
	Appendix C.....	90
	Appendix D.....	91
	Appendix E .....	93

## **LIST OF MAPS**

Map 1 Reclassified map of study area watershed for 1996 .....	34
Map 2 Reclassified map of study area watershed for 2006 .....	35
Map 3 Reclassified map of study area watershed for 2016 .....	36
Map 4 Location of the monitoring stations in the study area watershed .....	37

## LIST OF FIGURES

Figure 2.1 Conceptual map for the study.....	9
Figure 3.1 Comparison of Seattle Metropolitan Statistical Area landcover in 1986 and 2007 (Hutyra et al., 2011).....	27
Figure 4.1 Location map of study area watershed.....	30

## LIST OF TABLES

Table 1 Data Dictionary.....	38
Table 2 Changes in riparian landscape pattern within 100m riparian buffer.....	46
Table 3 Changes in riparian landscape pattern within 300m riparian buffer.....	49
Table 4 Correlation between 100m riparian landscape pattern and water quality parameters .....	53
Table 5 Correlation between 300m riparian landscape pattern and water quality parameters .....	53
Table 6 Summary Table for Total Nitrogen (TN) in 100m riparian buffer model.....	55
Table 7 Summary Table for Nitrate-nitrite in 100m riparian buffer model.....	57
Table 8 Summary Table for Total Nitrogen (TN) in 300m riparian buffer model.....	59
Table 9 Summary Table for Nitrate-nitrite in 300m riparian buffer model.....	61

# 1 INTRODUCTION

Riparian buffers are transitional vegetated zones between terrestrial uplands and aquatic ecosystems along rivers and different perennial or intermittent streams that provide a unique environment for the functioning of ecosystems which provide important services for human wellbeing including biodiversity, water quality, nutrient cycling, bank stabilization, flood mitigation, wildlife habitat, and various recreational uses (Gregory, Swanson, McKee, & Cummins, 1991; Jun & Wang, 2005; National\_Research\_Council, 2002b; H. Xu, Cai, Du, & Guo, 2021). Although the ecological importance of these zones along with wetlands has been widely recognized since the 1970s, unlike wetlands that are regulated under Section 404 of the Clean Water Act, 1972, riparian areas are not considered under any US federal regulatory land management programs. Thus, there are no formal guidelines to inform local and regional agencies in how best to protect, manage, and prevent degradation of these ecologically important areas.

Historically, when the European settlers first came to the United States, available fertile land and easy access to the water sources made riparian lands most attractive for development at the very first instance. Since then, with every wave of agriculturalization, industrialization, automation, and urbanization, these zones have been subjected to various anthropogenic activities and continuous land transformations. This has put tremendous pressures on these ecologically sensitive areas that are either lost completely to accommodate other urban or agricultural land uses or have degraded to such an extent that they are unable to perform the ecosystem services that are vital for human well-being. One such important ecosystem service is the regulating service of water purification (Millennium\_Ecosystem\_Assessment, 2005b) of aquatic ecosystems, including rivers, lakes, and streams. Water quality refers to the physical, chemical and biological properties

of water that are standardized to determine its usage for various purposes (Khatri & Tyagi, 2015). Water purification is recognized as an important ecosystem service that is required not only to provide clean, potable water for human consumption, and freshwater aquatic biodiversity, it is also valued as it supports a wide array of agricultural, industrial, mining, and recreational activities (Keeler et al., 2012; Pizarro, Vergara, Rodríguez, & Valenzuela, 2010); therefore, it is important to maintain the water quality of the aquatic ecosystems.

Out of the various factors impacting water quality of the aquatic ecosystems, land transformations in the form of land cover and land use changes in the catchment areas are the most significant (Cheng, Zhang, Shi, & Kung, 2022; Chu, Liu, & Wang, 2013; Kumar et al., 2019; Poff, Bledsoe, & Cuhaciyan, 2006). These transformations are brought about by both natural as well as human-induced processes. Natural processes include rapid shifts in temperature and weather patterns brought about by climate change, severe weather events like droughts, floods, wildfires, earthquakes, etc., weathering of rocks, atmospheric deposition or various biological factors; such processes result in alteration of various topographic features of the landscape like slope, soil type, bedrock sub-strata, and vegetation (Chu et al., 2013; Khatri & Tyagi, 2015), thus leading to land transformations. On the other hand, human-induced processes causing land transformations includes various anthropogenic activities resulting from the increased rates of urbanization, agriculturalization, and industrialization (Millennium\_Ecosystem\_Assessment, 2005a). The impact of land transformations on water quality of rivers and streams is further exacerbated in urban areas by the unprecedented growth in urban population, urban land modification, and urban expansion (W. Li, Shen, Tian, Liu, & Qiu, 2012; Volo, Vivoni, & Ruddell, 2015).

These landscape transformations result in change in landscape patterns, which comprises of two important components – landscape composition and landscape configuration. While

landscape composition refers to the amounts and diversity of different types of land covers, landscape configuration refers to the spatial arrangement of different land cover types within the landscape (Fahrig et al., 2011); both these components are variably affected by the land transformations. The changes to the landscape patterns from land transformations not only result in a change in the hydrological cycle of the aquatic systems by affecting the regional climates (du Plessis, Harmse, & Ahmed, 2014), they also impact the quality of water in these systems by affecting the rate, quantity and quality of runoffs flowing into them. Moreover, landscape patterns in the catchment areas impact both point sources such as wastewater treatment facilities, and non-point sources such as runoffs from impervious urban land covers in urban areas (Puckett, 1994; Wang, 2001), and thus affect the overall pollutant contents and levels in urban waters, subsequently affecting the quality of water in these ecosystems.

Landscape transformations also results in altering the riparian landscape patterns within a watershed. As riparian buffers are the final receiving grounds through which the runoffs traverse before entering the water systems, changing landscape patterns affect both the riparian vegetation, and its habitat, which are required to perform the regulating ecosystem service of water quality protection of the aquatic ecosystems within the watershed.

## **1.1 Problem Identification**

Owing to its significance in the protection of water quality, the impacts of different landscape patterns as well as landscape transformations have been widely documented by the researchers worldwide, for e.g., (Bylak et al., 2022; Fatehi, Amiri, Alizadeh, & Adamowski, 2015; Paul & Meyer, 2001; Watelet & Johnson, 1999). Studies investigating the inter-relationship between water quality parameters, and different components of landscape pattern began in the 1960s (Leopold, 1968). While earlier studies identified the impact of landscape composition and

morphometric features on different biological, physical, and chemical properties of water in the aquatic systems within a watershed (Allan & Johnson, 1997; K. Li et al., 2018; Townsend, Dolédec, Norris, Peacock, & Arbuckle, 2003; Zampella, Procopio, Lathrop, & Dow, 2007), recent studies confirmed that not only the quantitative variability of different land cover types, but also their spatial arrangement within the landscape impact the quality of surface water in a watershed; these studies have, thus, investigated the inter-relationships between spatial configuration of different land cover types and water quality parameters at variable spatial scales (Alberti et al., 2007; Chiang, Wang, Chen, & Liao, 2021; Gardner & Urban, 2007; Stryjecki et al., 2016; Zhong, Xu, Yi, & Jin, 2022) using different types of landscape metrics. Most of these studies have confirmed that a statistically significant relationship exist between landscape patterns and water quality parameters (Turner, 1989).

Along with the assessment of the impact of different landscape components on surface water quality parameters, several studies have also focused on understanding its variability at multiple spatial scales (Alberti et al., 2007; Tudesque, Tisseuil, & Lek, 2014; Zhong et al., 2022). The scales in these studies have ranged from “local or basin level to eco-regional scales” (Goldstein, Carlisle, Meador, & Short, 2007). However, the scale effect of landscape patterns on water quality lacks consensus as the relationship is complex and area specific (Griffith, 2002), and varies from one watershed to another (Shi, Zhang, Li, Li, & Xu, 2017). While some studies like Tong and Chen (2002) have found that the basin scale is a very useful and reliable scale to study the effects of various land uses on stream water quality parameters such as nitrogen, phosphorous, and fecal coliform, other studies have found that the sub-basin scale has a more relevant relationship with the water quality parameters (Jarvie, Oguchi, & Neal, 2002).

In the past two decades, several studies have assessed the linkages between different landscape features in varied spatial scales and quality of water in rivers and streams within a watershed (Baker, 2005; Blaszcak, Delesantro, Zhong, Urban, & Bernhardt, 2019; Cheng et al., 2022; Chiang et al., 2021; Chu et al., 2013; Fatehi et al., 2015; Jarvie et al., 2002; Kaushal et al., 2017; Khatri & Tyagi, 2015; Kumar et al., 2019; K. Li et al., 2018; Mayer, Reynolds, Canfield, & Mccutchen, 2005; Namugize, Jewitt, & Graham, 2018; Ou, Wang, Wang, & Rousseau, 2016; Reisinger et al., 2019; Shi et al., 2017). Despite increasing number of studies have shown the importance and relevance of the riparian zones in maintaining water quality, the impact of the landscape pattern of riparian zones on river and stream water quality in a watershed and at what scale is still not fully understood (Baker, 2005). Some of the reasons for this limited understanding are: a) uncertainty over ideal riparian buffer width to be considered; b) variability of observed landscape impacts with spatial scale (Xu, Yan, Wang, Hua, & Zhai, 2023); c) exogenous factors affecting water quality like characteristics of stream or river ecosystems. For example, a study conducted in the Ipswich River watershed of Massachusetts found that the water quality in the watershed was more significantly related to the solute concentrations found in the river than that of the riparian buffer land covers (Williams, Hopkinson, Rastetter, Vallino, & Claessens, 2005). And, d) temporal scale of analysis, i.e., there is dearth of knowledge linking riparian landscape components to water quality parameters temporally. Few studies that have focused on investigating the role of temporal changes in riparian landscape on water quality parameters have done so with respect to seasonal changes in water flow over a short period of time (Sliva & Dudley Williams, 2001; Sy & Quesada, 2020). Studies indicating the role of long term riparian landscape characteristics within a watershed region on river and stream water quality have been limited.

## 1.2 Study Rationale

As the Cedar River – Lake Washington watershed includes some of the major urban centers within the Pacific Northwest region of the United States, and has seen unprecedented growth and development since the onset of the IT industries towards the end of the 20<sup>th</sup> century, it represents an ideal case to study the impacts of riparian landscape characteristics on water quality in an urbanizing watershed. The intent of this study is to inform local, regional and state agencies about the conditions as well as changes in conditions of riparian zones and water quality of different aquatic systems within the watershed during a 20-year time period from 1996-2016. By exploring the relationship between riparian landscape patterns and water quality properties of streams and rivers in the watershed, this study can help determine the components of riparian landscape patterns that have significant associations with the water quality parameters and can predict future trends. As these parameters are important metrics to determine the quality of water, the study will be helpful for planners and future policy-makers to design appropriate policies for the management of riparian land covers to maintain and protect river and stream water quality within the watershed.

Under the “Critical Areas Ordinance” outlined in the Growth Management Act (GMA), 1990, five type of critical areas are required to be protected by different local governments within the state of Washington. They include wetlands, areas with a critical recharging effect on aquifers used for potable water, fish and wildlife habitat conservation areas, frequently flooded areas, and geologically hazardous areas; it does not include riparian zones as critical areas. As most of the included “critical areas” are contained within these buffers, a selected portion of these buffers receive protection under the law. If the findings of this study would suggest a strong correlation between riparian land covers and water quality parameters, riparian buffers as a whole could also be designated as “critical areas”, and human-induced land transformations would be restricted

within these buffers to protect them from further degradation, and also to maintain efficient water quality on the bordering aquatic ecosystem.

### **1.3 Research Questions**

In line with the problem statement and study rationale identified above, the overarching question that this study aims to answer is: **How do landscape patterns in the riparian zone affect the physical and chemical parameters of water quality in the Cedar River – Lake Washington watershed?**

The detailed research questions are as follows:

1. How have the riparian landscape patterns in the Cedar River – Lake Washington watershed changed between 1996-2016?
2. What changes in water quality have occurred in streams and rivers within the watershed between 1996 and 2016?
3. How are the two components of the riparian landscape pattern (composition and configuration) related to the different water quality parameters of streams and rivers in the Cedar river - Lake Washington watershed between 1996 and 2016?
4. How significant is riparian landscape pattern in explaining current trends in different physical and chemical parameters of water quality of streams and rivers in the Cedar river - Lake Washington watershed?

### **1.4 Thesis Outline**

To define the focal issue, the thesis begins with problem identification, providing rationale for conducting this study, outlining the research questions, and providing limitations of the study in Chapter 1. Chapter 2 provides a conceptual framework for the thesis along with my research

hypothesis. Chapter 3 introduces different concepts relating to riparian landscape and water quality parameters. It further provides an overview about the historic changes in LULC and water quality of rivers and streams within the study area watershed, and reviews the application of the current policies relating to riparian zones. Chapter 4, Research Methodology, is divided into two main parts: the first part introduces the study area, i.e., the Cedar River – Lake Washington watershed by providing details about its physical context, demographic overview and existing land use; the second part comprises data collection sources and techniques, data processing steps, and data analysis methods. Chapter 5 reports the final results from the analysis and attempts to answer the research questions introduced in Chapter 1. Chapter 6 presents a discussion about the final results. Finally, Chapter 7 contains a conclusion summarizing the research and provides recommendations for urban planning.

## **1.5 Limitations of the Study**

For this project, I focused on a part of the entire watershed WRIA 8, the Cedar River – Lake Washington watershed region in Washington state to conduct my analysis. In order to conduct this study, I have used secondary datasets for the study area watershed by considering data for the years 1996, 2006, and 2016. Further, the scale of analysis selected for this study is limited to riparian scale, where different analyses are conducted for 100m, and 300m riparian buffers. Also to maintain uniformity across all stations, the length of the buffer is fixed to 1km upstream from the measuring stations.

## 2 CONCEPTUAL FRAMEWORK

To understand the impact of the riparian landscape patterns on physical and chemical properties of stream and river water in the Cedar River – Lake Washington watershed, I develop a conceptual map as shown below in Figure 2.1.

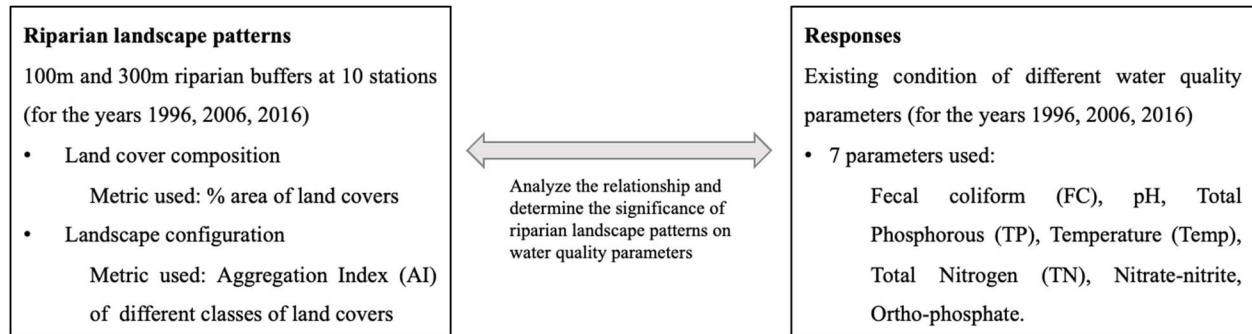


Figure 2.1 Conceptual map for the study

As explained in Chapter 1, land transformations from urbanization as well as different natural processes also impact riparian landscape patterns. As these patterns determine the vegetative variability and habitat species within the riparian areas, the water quality and surface runoffs into different water channels within the watershed might also be impacted.

I hypothesized that

1. Due to land use changes, the riparian landscape patterns in the study area watershed have changed 1996-2016.
2. Physical and chemical parameters of water in streams and river in the watershed have depreciated over the 20-year time frame.
3. The landscape composition and configuration of the riparian area are correlated with different water quality parameters.

4. The landscape composition and configuration of the riparian area are robust predictors of future trends of different physical and chemical parameters of water quality of streams and rivers in the Cedar river - Lake Washington watershed.
5. The correlation and significant associations of riparian landscape patterns with water quality parameters change with riparian scale used for analysis.

### 3 LITERATURE REVIEW

This section introduces different concepts relating riparian landscape and water quality parameters in a watershed by providing an understanding about the effects of urbanization on the ecology and hydrology of the riparian landscapes. Further, this chapter provides an overview about the historic changes in LULC and water quality of rivers and streams within the watershed. In addition, this chapter also reviews the application and management of the current policies, and governmental guidelines relating to riparian zones in the past few years; thus analyzing the relevance of such studies for planners and policy-makers while formulating policies for efficient water quality and riparian land management in the future.

In order to provide a systematic literature review, this chapter has been divided into three broad sub-sections: riparian landscape, water quality, and the history of LULC changes and water quality in the study area watershed.

#### 3.1 Riparian Landscape

The term “riparian” comes from the Latin word “*ripa*” meaning bank of a river (S. J. Capon, 2020). Since early 19<sup>th</sup> century, the term has been used with water law, where an owner of a property along the bank of a river, stream, lake, or alongside the bank of any water body is given the right to use that portion of water (Merriam-Webster, n.d.). In a study conducted by the National Research Council in 1995, the researchers recognized the ecological significance of riparian landscapes in comparison to wetlands, but only designated the water saturated areas under the typology of wetlands; the drier areas that were located on the banks of a water body were not recognized for any protection, unlike the wetlands (National\_Research\_Council, 2002b). As riparian areas are defined by their location in context of aquatic and upland features, rather by the

hydrologic composition of their soil, the policies and programs aimed at wetland protection specifically, did not protect the riparian areas. Therefore, in order to provide proper protection for the riparian zones, another study was conducted by the Council in 2002 to study riparian zones in entirety, as an outgrowth to the previous study on wetlands (National\_Research\_Council, 2002b).

The committee involved in the study defined riparian areas as follows:

“Riparian areas are transitional between terrestrial and aquatic ecosystems, and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence)”.

The above definition for riparian zones clearly identifies gradients of environmental conditions across the breadth of a riparian ecosystem. Under ideal conditions, a healthy stream or river corridor not just encompasses the active water channel, it also includes narrow landscape strips, commonly known as riparian buffers that provide habitat to a wide range of plant species and wildlife within, and perform a range of ecological functions, including water quality protection.

### *3.1.1 Riparian Landscape Patterns and its Functions*

As defined in Chapter 1 of this study, landscape pattern comprises of two important components – land cover composition, and landscape configuration. Without human interventions, riparian landscape pattern is shaped by “the interaction of many climatic, hydrologic, geomorphic and biological factors” (National\_Research\_Council, 2002c; Pettit & Naiman, 2007), and contains woody debris, floodplains, and different types of vegetative covers. The landscape features like slope, soil type, size, along with the landscape pattern of the entire watershed as well as “channel

morphology, sediment dynamics and floodplain structure” largely affect the riparian vegetation and its habitat (S. Capon, James, C., Reid, M., 2016). Because of many underlying factors impacting riparian zones simultaneously, and its variability in spatial and temporal scale, it is very complex to define the extent and overall structure of riparian landscapes (S. J. Capon, 2020; Nakamura, 1995).

Typically, riparian strips are composed of a vegetative land cover such as forests, shrubs, or wetlands, a water saturated land cover like aquatic beds, floodplains, or bare lands containing wood debris, and gravel bars with variable depths of water table. The spatial configuration in which these land types are arranged within the landscape corridors are not constant, and varies with the wide variety of terrestrial and aquatic ecosystems found across numerous watersheds. However, because of their proximity to the water bodies they border, and their unique hydrologic and geomorphic characteristics, riparian landscapes perform a range of critical ecological functions; most of these functions are dependent on the type of riparian vegetation and its properties relating to its root depth and structure, leaf litter, stem density, etc. (S. J. Capon, 2020). These functions include climate regulation (Brosofske, Chen, Naiman, & Franklin, 1997; Pettit & Naiman, 2007), prevention from hydrologic hazards like cyclones, hurricanes, storm surges, etc. (S. J. Capon et al., 2013; Nilsson & Svedmark, 2002; Stromberg, 2001), river and stream bank stabilization by reducing erosion, increasing soil cohesions, and protecting top soil to get washed away by surface runoffs and flood waters (Hubble, Docker, & Rutherford, 2010; Krzeminska, Kerkhof, Skaalsveen, & Stolte, 2019; Malanson, 1995), and providing ecological heterogeneity to support a wide variety of biodiversity than the surrounding terrestrial ecosystems (Bennett, Nimmo, Radford, & Wilson, 2014; Decamps, Joachim, & Lauga, 1987; Woinarski et al., 2000).

Along with the above mentioned ecological functions, another key function performed by riparian landscape is water quality regulation (S. J. Capon & Pettit, 2018; Mayer, Reynolds, McCutchen, & Canfield, 2007). In this study, I have focused on this function of the riparian landscapes in the study area watershed. Riparian vegetation and its soil composition play a significant role in performing this function by: a) filtering surface runoffs from terrestrial ecosystems in the uplands before entering the aquatic ecosystems, b) trapping excess nutrients and sediments with the help of the type and structure of riparian vegetation, litter and woody debris, and c) through nutrient uptake by the local plant communities and soil microbial activity (Lowrance et al., 1984; Pinay & Decamps, 1988; Pinay, Roques, & Fabre, 1993).

### *3.1.2 Factors influencing Riparian Landscape Functions*

It is important for the riparian landscapes to maintain their hydrological, geomorphic and biological structure to sustain the necessary conditions required to perform the vital ecological functions. However, because of the impact of many natural as well as human-induced stressors, the structure of these landscapes is augmented; thus, not allowing them to function properly. For the sake of this study, we would concentrate on the human influence on riparian landscapes.

Rapid increase in human population, especially in and around urban agglomerations, have put tremendous pressures on various natural ecosystems, and have in a major way contributed to the alteration in the overall structure and ecological functioning of these systems. Out of the various threatened ecosystems, riparian ecosystems are considered to be amongst the most beneficial, yet most modified and degraded ecosystems in the world (Tockner & Stanford, 2002). Continuous and rapid urban growth, agricultural and industrial advancements, along with the human impacts of climate change from increasing average global temperatures to alteration in the hydrological cycles have resulted in irreversible changes in the natural ecology of these

ecosystems. Since the onset of the industrial era by the European settlers, there has been a drastic decline in the total acreage as well as the condition of riparian lands across the United States (National\_Research\_Council, 2002a). The changes to the riparian landscapes are reflected in the quality of adjacent water channels across the country, where studies suggest only about 2% of the nation's streams and rivers are classified as having high water quality (Benke, 1990; EPA, 2000). Below, I have given a gist of the human influences to the riparian landscapes:

*a) Urbanization:*

Widespread urbanization, and rapid growth of cities have profound impacts on the watershed hydrology and vegetation that consequently affects the structure and functioning of riparian landscapes (National\_Research\_Council, 2002a). Currently, more than 50% of the world population is urban, and is expected to be around 70% by 2050 (UN\_DESA, 2018). The urban character that impacts riparian landscapes the most is the imperviousness of the developed land covers. Natural land covers like forests and wetlands have the water retention capacity to store excess water from precipitation in its vegetative roots as well as in the form of groundwater in aquifers; as the percolated water traverse across this land cover, it deposits excess nutrients and sediments into the soil, and clear water enters into the water system. However, when this natural land cover is converted into developed urban land covers, where a significant portion of the land area is covered by concrete, asphalt, and other constructed materials, the porosity of the land cover decreases. With increased imperviousness, groundwater recharge and infiltration capacity of land decreases, while overland peak volume of water and surface runoff rates into water channels increases; thus causing rapid degradation of the water quality in the rivers and streams in urban areas. The changing landscapes in urbanizing watersheds have deleterious impacts not only on the aquatic ecosystems, it also alters the hydrology of riparian areas. To accommodate increased

surface runoff frequencies, volumes and peak flow rates, the water channels increase their cross-sectional area; thus causing erosion of the banks, increase in sediment and nutrient loading, and riparian habitat degradation (Schueler, 1987, 1994).

Along with the urban land transformations, increase in urban drainage and transportation infrastructure also results in augmenting the structure and functioning of riparian areas. For the purpose of water management in urban areas, several strategies have been implemented to efficiently transport wastewater and stormwater. These strategies could be broadly categorized into two categories: gray infrastructure, which include conventional piped systems for drainage and conveyance of wastewater and stormwater to a discharge point (Hale, Turnbull, Earl, Childers, & Grimm, 2015; Svendsen, Northridge, & Metcalf, 2012); and green infrastructure that uses nature-based solutions, including wetlands and riparian buffers to manage stormwater. Both these categories of urban drainage infrastructure have variable impact on the structure and functioning of riparian landscapes. While piped systems or the gray infrastructure often discharge the effluents directly into the river and stream water channels, completely circumventing riparian zones (National\_Research\_Council, 2002a) and leading to point source pollution in the water, natural and artificially constructed green infrastructure systems often fail to function efficiently due to lack of proper management and pollutant overloading (Paul & Meyer, 2001). In either of the two cases, the water quality of the receiving river and stream corridor is adversely affected by not only increasing the quantity, quality and rate of flow, it also impacts riparian environments, and thus its vegetation and wildlife.

Lastly, the role of urban transportation networks in the form of water transportation, roadways and rail networks on riparian landscapes, and river and stream corridors could not be ignored. Rivers across the United States were used for transporting people and goods since the

European settlers first sailed into the country (Groffman et al., 2003). Boats, canoes, ships, and other watercraft were used according to the quantity of load they carried. Initially, river and stream networks were used to transport logs of timber to market from the place of their harvest. Although it was considered to be a cost-effective method of transportation, the downstream movement of the logs usually involved clearing of the riparian vegetation, including large trees, and bank erosion because of channelization (National\_Research\_Council, 2002b; Sedell, 1985). Later, rise of the auto industries and rapid suburbanization led to the construction of a widespread systematic network of roadways across the country which often has far-reaching and permanent impacts on the riparian conditions. The impacts include complete removal of riparian vegetation to pave way for roadways, many of which are constructed along major watercourses, alteration of topography, and hydrologic modifications altering the infiltration capacity of riparian landscapes (Forman & Deblinger, 2000). Even the construction of road and rail networks outside the riparian boundaries within a watershed produces disturbances to the hydrologic regimes, and increased imperviousness transfers excess surface runoffs and its impurities into the water channels.

In totality, the impacts of urbanization on riparian landscape is variable, and largely depends upon the historic patterns of development, existing hydrologic and geomorphic conditions, and also the geographical context of the riparian areas within the watershed (Forman & Deblinger, 2000; Pizzuto, Hession, & McBride, 2000; Trimble, 1997).

*b) Hydrologic alterations:*

These include changes to the natural flow patterns, and hydrologic regimes of the aquatic systems in a watershed. These alterations are a result of

- construction of dams and levees for purposes like hydropower generation, flood control, irrigation, etc.,

- construction of bank stabilization structures like rip-raps and jetties by clearing up the vegetative banks and filling them with impervious land material for protecting the banks against erosion, and
- channelization by “widening and deepening the stream channel” (Pierce & King, 2013) for altering the fundamental geomorphic and hydrologic character of a water channel to suit various human needs.

Such man-made alterations to the natural river and stream corridors, nevertheless, result in permanent damages to the riparian areas and the bordering water systems by controlling flood or flood-like conditions in riparian landscapes; thus altering the overall temperature, surface water and groundwater flows, and material transport to the water channels responsible for the survival of riparian vegetation and its wildlife.

*c) Agriculture:*

In the United States, the impact of agriculture, along with increasing rates of urbanization is considered to be the largest human influence on riparian landscapes and its functioning (Dillaha, Reneau, Mostaghimi, & Lee, 1989). Being an excellent source of superior soil quality and having the added advantage of easy access to a water resource have attracted farmers and food industries alike into the riparian buffers. Conversion of land to agricultural use significantly affects the infiltration quality of these areas by destroying the riparian vegetative cover, and affecting the cohesion properties of riparian soil. Also, food industries encourage farmers to use toxic chemicals in the form of pesticides and other chemical catalysts to boost their production, which leads to nutrient overloading in the soil; this reduces the infiltration capacity of the soil, and excess nutrients traverse along with the runoffs directly into the water channels, leading to non-point source pollution in the water systems. Removal of the top soil containing important organic matter

for various agricultural activities also increases the velocity and quantity of surface runoffs flowing into the fluvial systems; thus increasing the chances of water pollution in the rivers and streams. In addition, withdrawal and slow recharge of excess groundwater leads to lowering of water table, which further impacts landscape vegetation and the wildlife within (National\_Research\_Council, 2002a). Along with the impacts of agriculture, grazing by farm animals and domestic livestock on riparian lands also results in similar alterations to the riparian landscapes; excess grazing and trampling by these animals result in altered hydrologic regimes, redistribution of sediment and nutrient inputs, and reduction in biotic richness (Kauffman & Pyke, 2001).

*d) Forest operations:*

Many forest related activities like timber harvest and recreational activities like hiking, camping, fishing, etc. has resulted in alteration of long term composition and bio-physical character of riparian forests, and thus the structure and function of these systems (Ralph, Poole, Conquest, & Naiman, 1994). Also, the construction of temporary or permanent transportation routes along water channels can alter the long term character of riparian forests (Adams & Ringer, 1994). Forest operations as well as clearing of riparian forest land covers into urban or agricultural land uses often produces deleterious outcomes by removal or alteration of riparian vegetation, decreased sediment retention, and increased nutrient flows into the river and stream networks (Murphy, 1995). Clearing of the tree canopy from the water banks also results in increasing the stream and river water temperature, and increased non-native biodiversity within the riparian zones (National\_Research\_Council, 2002a).

### *3.1.3 Delineation of Riparian Landscape and its Significance*

Although the riparian zones are said to comprise portions of river or stream channels along with the areas located on the banks of the water channel, the spatial extent of these zones lack consensus. According to S. J. Capon (2020), the entire catchment area of a given water body could be considered a “riparian area” to some extent as it is influenced by the aquatic ecosystem to some degree that depends upon the distance from the water channel, and the influence decreases as one moves away from the aquatic system. The spatial extent or the zone of influence includes the width of the zone that may or may not vary for a water system for different seasons throughout a year. For instance, the perennial water system maintains a high water table throughout the year, however for intermittent systems, the water table reduces, which would then affect the riparian vegetation, and hence its spatial extent. Because many researchers have realized and expressed their concerns over the heterogeneity of this zone, it has been widely accepted that delineation of riparian zone is not a universal process and is very much dependent on the attribute considered for its delineation, i.e., physical location or ecosystem function (Everest & Reeves, 2006). Beyond these attributes, delineation of riparian buffers also takes into account climatic features of the geographical location of the water system, i.e., arid, semi-arid, or forest zones, size of the stream, and its position in the drainage watershed (Naiman & Decamps, 1997).

In spite of the ambiguity surrounding delineation of riparian buffers, it is worth mentioning that it is considered an important step in watershed management for the protection of ecologically sensitive areas like riparian zones against human-induced transformations that would in turn impact its overall structure as well as the their ecological functioning.

### 3.1.4 *Status of Riparian Areas*

After the enactment of Emergency Wetlands Resources Act by the Congress in 1986, the department of U.S. Fish and Wildlife Service mapped wetlands across the United States under the National Wetland Inventory program. These inventories provided the current status and trends in wetlands across the nation, and have also received support from various state, regional, local, and non-governmental agencies in their effort to maintain “No Net Loss” federal policy for wetland protection. However, riparian areas across the nation have not received similar attention; studies on assessment of riparian zones are sparse and limited. The level of protection that different regulatory and legal mechanisms provide under various federal, state, and local agencies vary (National\_Research\_Council, 2002b).

Within the state of Washington, especially the Puget Sound watershed, the predominant land cover is forests, and forest operations along with the recent growth in urbanization are major land use activities (Alberti et al., 2007); these are also the important stressors that impact the landscape patterns in the riparian areas within the watershed. The Washington Department of Fish and Wildlife (WDFW) is responsible for the protection of fish and wildlife species within the state. However, it is not entitled over the protection of fish and wildlife habitat, which largely includes riparian areas. Therefore, many voluntary organizations along with various state programs like State Environmental Policy Act (SEPA), Growth Management Act (GMA), Forest Practices Act (FPA), Shoreline Management Act (SMA), and similar planning processes provide assistance to local and regional agencies to protect different types of “critical areas” within the state (Knutson, 1997). Although riparian areas, in their entirety has not been mentioned as a critical area under all the state programs, SMA and FPA have recognized their importance along with wetlands and other ecologically sensitive areas; thus, these agencies provide assistance relating to riparian land

management to landowners, agencies, governments, and members of the public in these buffers. In spite of these efforts, because of lack of a federal regulatory mechanism to enforce these developmental guidelines for riparian zone management, both their quality and quantity has been affected in the past; this in turn affects the ecological functioning of these ecosystems.

### **3.2 Water Quality**

Water is an odorless, tasteless, transparent liquid that forms streams, rivers, lakes, seas, oceans, etc., which all together makes up almost 70% of the Earth's surface. NOAA defines water quality as the "condition of water" in their natural state that includes their physical, chemical, and biological properties which is required for a designated use such as human consumption, recreational purpose, or for prevailing of different aquatic life forms. It is measured by collecting water sample from a water body and comparing its composition with water quality standards and guidelines defined for a particular use. Good water quality not only enhances health in all living beings, it also ensures overall protection of different ecosystems that supports diverse life forms.

Commonly, water comprises "dissolved solids" which are naturally occurring minerals and salts, and some dissolved gases like oxygen and radon. According to an article published in U.S.G.S. (2001), dissolved solids can be of 3 types: common constituents such as calcium, sodium, bicarbonates, and chlorides; plant nutrients such as nitrogen and phosphorus; and trace elements such as selenium, chromium, and arsenic. The article suggests that while common constituents are generally not considered harmful to human health, they can affect the taste, smell, and clarity of water; plant nutrients and trace elements, on the other hand, can negatively affect human health and aquatic life, if they exceed permissible limits as stated in the standards and guidelines. Dissolved oxygen limits are also a requirement for adequate water quality; however, radon gas in

drinking water supply, could pose severe health risks for humans, once it exceeds the permissible limits (U.S.G.S., 2001).

The sources of water quality degradation could be categorized as point and non-point source pollution. According to the U.S. Environmental Protection Agency (2000), point source pollution is defined as “any single identifiable source of pollution from which pollutants are discharged”. This may include pipelines from sewage treatment plants and factories. The effluents discharged from a factory are either treated (i.e., when the effluents are toxic) or directly released (i.e., when effluents are non-toxic) into the water bodies. Non-point source pollution, on the other hand, refers to the diffused sources of water pollution that enter into the natural waters through “land runoff, precipitation, groundwater recharge, atmospheric deposition, drainage, seepage or hydrologic modification”. The runoffs that contribute to water pollution are either urban runoffs that carry oil, dirt from urban land surfaces, like pavements, roads, parking lots, etc. or agricultural runoffs that carry excess nutrients from the soil using plant fertilizers, and other organic and inorganic matter. Either way, both the sources lead to increase in the nutrient and sediment composition of naturally occurring water, thus rendering them unfit for a particular use like drinking or sustaining a particular type of biodiversity.

### *3.2.1 Water Quality Standards*

Water quality standards are important parameters provided by “state, territorial, authorized tribal or federal” agencies in association with the U.S. EPA to evaluate the existing condition of a water body against its designated use (U.S.G.S., 2001). They consist of three core components: “designated uses of a water body, criteria to protect designated uses, and antidegradation requirements to protect existing uses and high quality/high value waters” (EPA, 2021). Designated uses of a water body can be further categorized as:

- a) Public drinking water supply,
- b) Recreational purpose,
- c) Protection and propagation of aquatic life forms,
- d) Agricultural, industrial, navigational, and other purposes.

The criteria describes the permissible concentration of different pollutants found in the water bodies specific to a particular region. These are numeric values and are decided by the agencies after scientific evaluation of those pollutants in water. Basically, the numeric values represent the tipping points required for the water bodies to maintain their water quality, exceeding or failing which could cause serious impacts to the physical, chemical, and biological condition of water in the water body; thus, in turn it affects the existence of the dependent ecosystems. Antidegradation requirements further provides a framework required to maintain good water quality in the water bodies. These are mandates taken from the Clean Water Act, the federal law in the United States to protect the nation's water against water pollution.

### *3.2.2 Washington State Standards and Guidelines for Water Quality*

The Department of Ecology is the primary agency in the state of Washington that provides standards and guidelines in accordance with the guidelines provided by U.S. EPA to protect the state's waters by setting permissible limits on various pollutants found in water bodies. The Department maintains standards for both surface as well as groundwater. Planning authorities of cities, counties, regions, and states, functioning within its jurisdiction are required to follow these standards. They issue permits to all the point source pollution dischargers. However, in order to monitor non-point source pollution in the waters, there are monitoring stations that collect and maintain daily, weekly, monthly and/or yearly data at all the strategic locations.

The freshwater quality standards for surface waters for the State of Washington (US\_EPA, 2022b) are as follows:

- Fecal coliform: should not exceed 100CFU/100ml
- pH: should ideally be between 6.5 to 8.5
- Total phosphorous: should not exceed 4mg/l
- Total nitrogen: should not exceed 10mg/l
- Temperature: should ideally be between 13°C to 22°C.

However, there are many exceptions to these criteria as mentioned by the U.S. EPA.

### **3.3 Historic Changes in LULC and River and Stream Water Quality in the Study Area Watershed**

#### *3.3.1 LULC Changes*

The Office of Coastal Management (OCM) under National Oceanic and Atmospheric Administration (NOAA) uses high resolution satellite imagery to document coastal land cover and how it changes over time. According to their report, in the U.S., 77,755 square miles (almost 50 million acres) of land changed in land cover type between 1996 and 2016 (NOAA, 2021b). In order to document these changes, NOAA's Climate Change Analysis Program (C-CAP) was created in 1992 to generate land cover inventories at regular intervals. As my study area watershed, lying within Water Resource Inventory Area (WRIA) 8, is located on the north-western coast of the United States, land cover information is provided under that program.

Consequently, in 2010, the King County Department of Natural Resources and Parks developed a land cover change analysis report for WRIA 8 in 2010 to identify changes in forest land cover and determine the impervious land cover change in the riparian zones within the sub-

basins of the watershed between 1991 and 2006 (Vanderhoof, Stolnack, Rauscher, & Higgins, 2011). According to the report (2011), most of the decline in forest land cover during the time period happened in the Sammamish basin (outside the study area), and Lower Cedar Sub-basin of the Cedar River – Lake Washington basin (study area). It also suggests an increase in impervious area in the identified riparian zones of the 54 sampled streams within the basin.

Since the adoption of Growth Management Act by the State of Washington in 1990, unlike the local governments of other states where the Act has not yet been adopted, the local agencies, here, are provided with a framework for regulating unplanned growth that curbs nuisances like urban sprawl, loss of valuable land cover, increase in traffic related problems, etc., especially areas around “critical areas”. However, as suggested, in the report (2011), there is a loss of forest land resources in WRIA 8 that includes our study area; although the conversion of forest land to other urban land uses has occurred within Urban Growth Area boundaries where land conversion is expected. In spite of these regulations for land management, unprecedented growth in urban population has put tremendous pressure on the ecosystems and their services, one of which service is that of maintaining the water quality of water systems within the watersheds.

The map in Figure 3.2 is taken from the journal article published by Hutyra, Yoon, Hepinstall-Cymerman, and Alberti (2011); it shows a comparison of the land covers of Seattle Metropolitan Statistical Area, 20 years apart. It suggests that not only has there been an increase in urban growth in the region, there has also been an increase in the intensity of urban growth in the region, i.e., there is an increase in the urban population density. It also shows that the eastern part of Lake Washington sub-area and the Lower Cedar Basin within my study area has undergone tremendous growth in urban land covers. Therefore, it is important to study how, within the study area, riparian landscape pattern has impacted the quality of urban waters within the watershed.

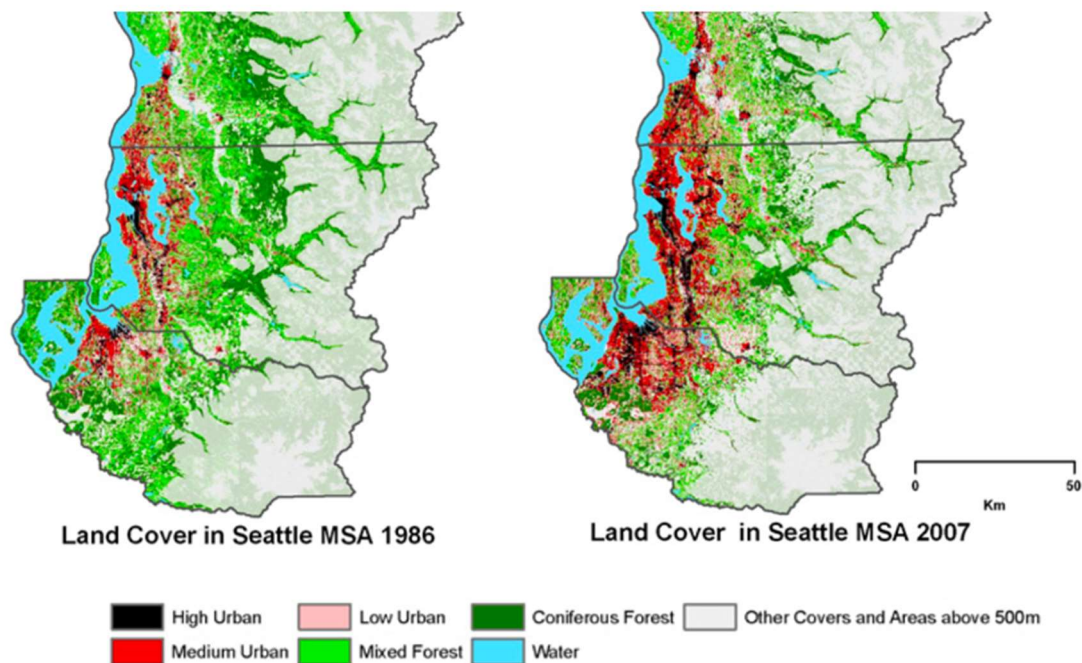


Figure 3.1 Comparison of Seattle Metropolitan Statistical Area landcover in 1986 and 2007  
(Hutyra et al., 2011)

### 3.3.2 Changes in Water Quality

In a study conducted by King County in 1993, it was suggested that the Lower and Upper Cedar basins of the study area watershed have shown a very high quality in the past, and they had been classified as Class A (excellent) and Class AA respectively. All the water in the state of Washington are protected for its various beneficial uses, and maintained under the Federal Clean Water Act, 1972 and the Washington State water quality standards. The Cedar River and its tributaries are used for various uses like domestic, industrial, agricultural, aquatic habitat, recreation, navigation, etc. The report also suggests that Cedar River basin was “ranked as the highest priority watershed in King County for action to address non-point source pollution” (King\_County, 1993). According to it, unless proper preventive measures are taken, the concentration of non-point source pollutants would increase as a result of rapid change in LULC across the County.

Lake Washington, on the other hand, is one of the largest freshwater lakes in the King county that receives its water from two major rivers, the Cedar River in the south, and Sammamish River in the north. Along with these two major rivers many other small streams surrounding the lake drain into the river. Water quality in the Lake Washington have been impacted by human interventions as well as biological processes in the past (Abella, 2016). Firstly, the Cedar River was diverted into the Lake after the construction of Ship Canal in 1916. This river diversion significantly impacted the nutrient and sediment loading in the Lake as the downstream water quality is the most impacted across the entire river channel. Secondly, the Lake received increasing amounts of sewage effluents from the surrounding urban areas that resulted in “eutrophication and decreasing water quality of the Lake” (Abella, 2016) because of high concentrations of phosphorous in the water samples collected during the mid-twentieth century. Lastly, the last restoration project was implemented by the King County agencies where the effluents were diverted in to the surrounding treatment plants setup in Renton. The project was a success as the water quality and transparency levels in the lake significantly improved (Edmondson, 1991).

## 4 RESEARCH METHODOLOGY

### 4.1 Study Area Overview

In order to answer the overarching question about the importance of maintaining the natural, undisturbed riparian landscapes in protecting the surface water quality of streams and rivers, I selected Cedar river – Lake Washington watershed as my study area watershed. It comprises one of the largest lakes in the King county, the Lake Washington and its largest tributary, the Cedar River along with other smaller lakes, streams and creeks. It is a part of the larger Cedar-Sammamish watershed, that is represented as Watershed Resource Inventory Area (WRIA) 8 in the state of Washington and is one of the HUC 12 regions represented by the U.S. Geographical Survey. There are 62 WRIsAs in the state of Washington that has been delineated by the Washington State Department of Ecology in cooperation with other state natural resources agencies (Department\_of\_Ecology). These major state watershed boundaries were legally enforced in 1971 “to be used as the basis for state management purposes” (LandScope\_America).

#### 4.1.1 *Geographical Context*

The study area watershed is geographically located in the U.S. Pacific Northwest. It is part of the larger Puget Sound basin, that has experienced rapid urban expansions and population outburst in the past few decades, owing to the onset of major ICT industries in this part of the country. The watershed contains parts of some of the major cities in the region like Seattle, Bellevue, Kirkland, Renton, etc. that accommodates a large portion of its urban population. Interestingly, along with high rates of urban growth, the watershed also encompasses a vast area of green land cover comprising of several forests, wetlands, grasslands, and shrubs. The sharp

gradient between natural as well as urban land covers in the watershed makes it an ideal place for my study.

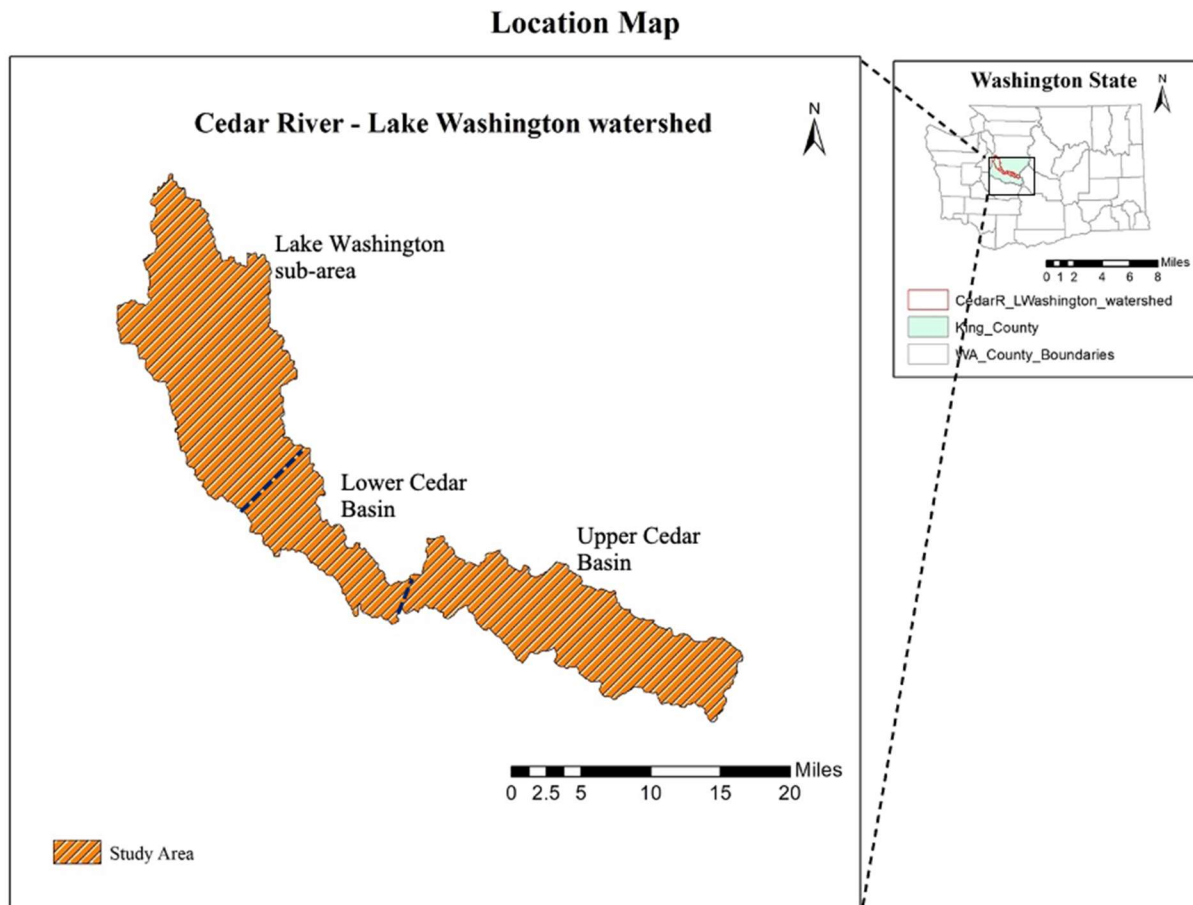


Figure 4.1 Location map of study area watershed

The watershed is primarily located in the King County, with a very tiny portion in the top spreading into the Snohomish county as shown in Figure 4.1. The lower part of the watershed comprises of the mouth of Cedar River, and thus forms the Upper Cedar Basin. According to the Salmon Conservation and Restoration project initiated by the King County Department of Natural Resources and Parks (2009), this part covers almost one-third of the total area of the watershed, and is mostly undeveloped natural land, owned by the city of Seattle, and is protected from land development and commercial timber harvest. Also, this is the source of drinking water supply for

the majority of the city of Seattle residents (King\_County, 1993). Less than a third portion in the middle of the watershed is the Lower Cedar Basin. Majority of this portion comes under unincorporated King County land area; the rest belongs to the city of Renton. The rest of the upper areas of the watershed are demarcated as Lake Washington sub-areas. This portion of the watershed have been largely urbanized; while the western side of the lake belonging to the city of Seattle started development since early 1900s, the eastern shore of the lake consists of rapidly urbanizing cities like Renton, New Castle, Bellevue, Kirkland, Kenmore, and many other small towns that has seen many recent urban developments. The majority of the land area around the lake is primarily used for residential purposes, except for a few land parcels which accommodate commercial and industrial land uses (Parks, 2009).

#### *4.1.2 Demographic Conditions*

The WRIA 8 accommodates almost 22% of the state's population (US\_EPA, 2022a), i.e., as the population of the state is 7.7 million (US\_Census\_Bureau, 2021), the region's population is around 1.7 million. According to Census 2010, the population density of the area surrounding Lake Washington is the highest in the state.

#### *4.1.3 Land Use*

The land use of the study area watershed displays a stark gradient between urban, rural, and forest uses. As indicated earlier, its top third portion is primarily dedicated to residential uses, while its bottom third is dedicated to unmanned forest purposes. However, the middle portion of the study area forming the Lower Cedar basin comprises of a mix of urban, rural and mixed uses. Because of a dramatic history of land use changes and its adverse impacts on the surrounding aquatic and terrestrial ecosystems, especially in this portion of the watershed, the Department of

Public Works at King County has also developed a “Current and Future Conditions Report” for the Lower Cedar Basin in 1993. According to the Report (1993), the land uses for this portion of the watershed have transformed from “historic logging of forests and mining of coal, sand, and gravel to ever-expanding urban and semi-rural communities”. The report also predicted a rapid population growth in the region converting pervious natural landscapes to impervious urban land uses, mostly dedicated to single-family housing, industrial expansion, and large commercial and parking lots. The lower Cedar Basin has minimum forest land uses; majority of the area is dominated by single-family residential uses and rural areas, as was predicted in the Report (1993).

## 4.2 Research Methods

In order to analyze the relationship between riparian landscapes and water quality parameters, I use a non-experimental quantitative research design approach. As outlined by Creswell and Creswell (2018), a quantitative design approach is appropriate when a researcher seeks to understand the relationships between variables.

### *Study Variables*

- Independent variables: 2 components of riparian landscape pattern measured for two different scales of riparian buffers, 100 meters and 300 meters –
  - % of land covered (i.e., land cover composition) of riparian land covers categorized as urban or natural for years 1996, 2006, and 2016
  - Aggregation Index (AI), a metrics to measure landscape configuration for riparian land covers for years 1996, 2006, and 2016.
- Dependent variables: Water quality parameters.

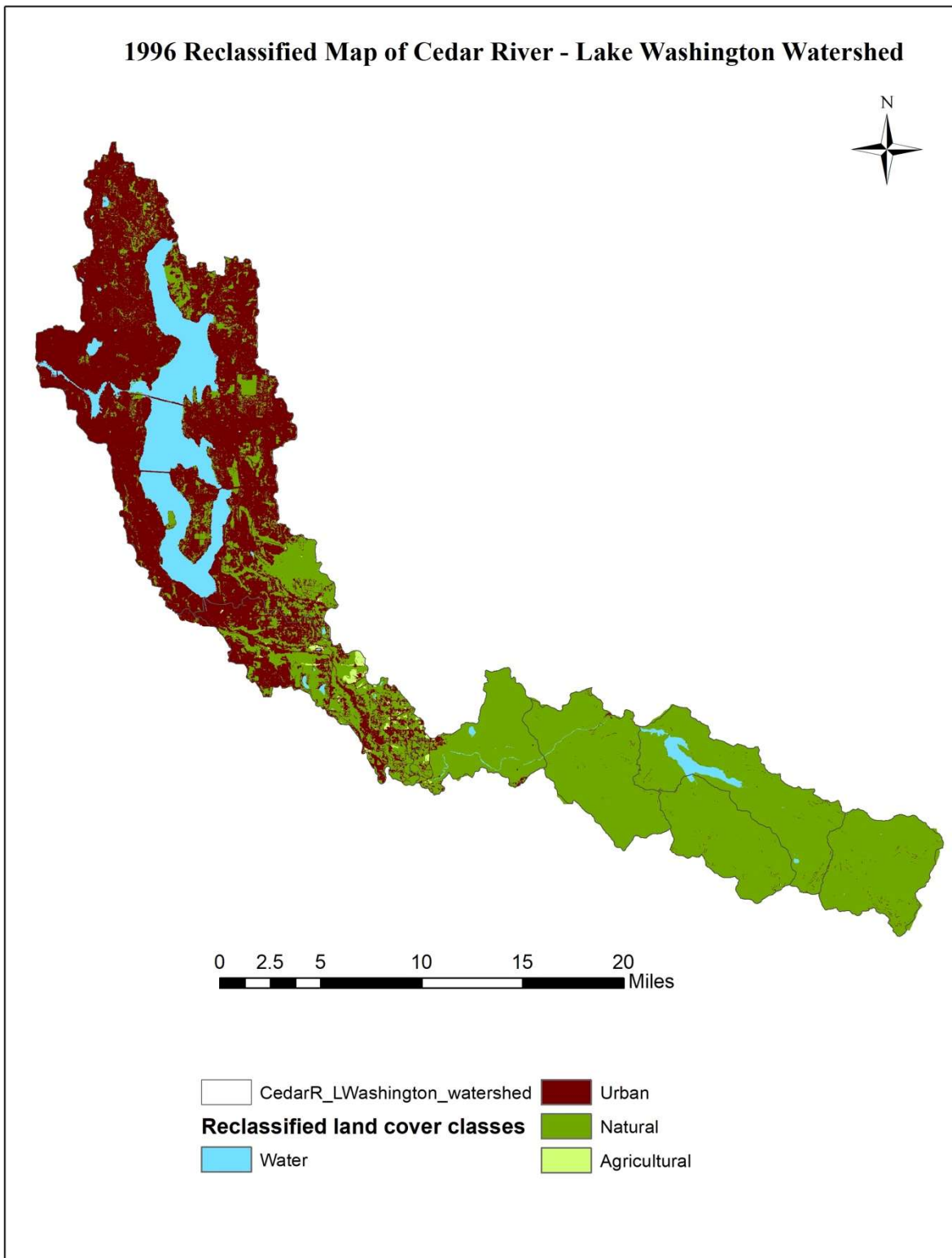
- For this study, I used 7 water quality parameters that represented the physical and chemical state of water at the time when the data was recorded. These parameters are: fecal coliform (FC: CFU/100ml), pH, total phosphorus (TP: mg/l), temperature (Temp: °C), total nitrogen (TN: mg/l), nitrate-nitrite ( $\text{NO}_3 - \text{NO}_2$  : mg/l), and ortho-phosphate (mg/l).

## 4.3 Data Collection

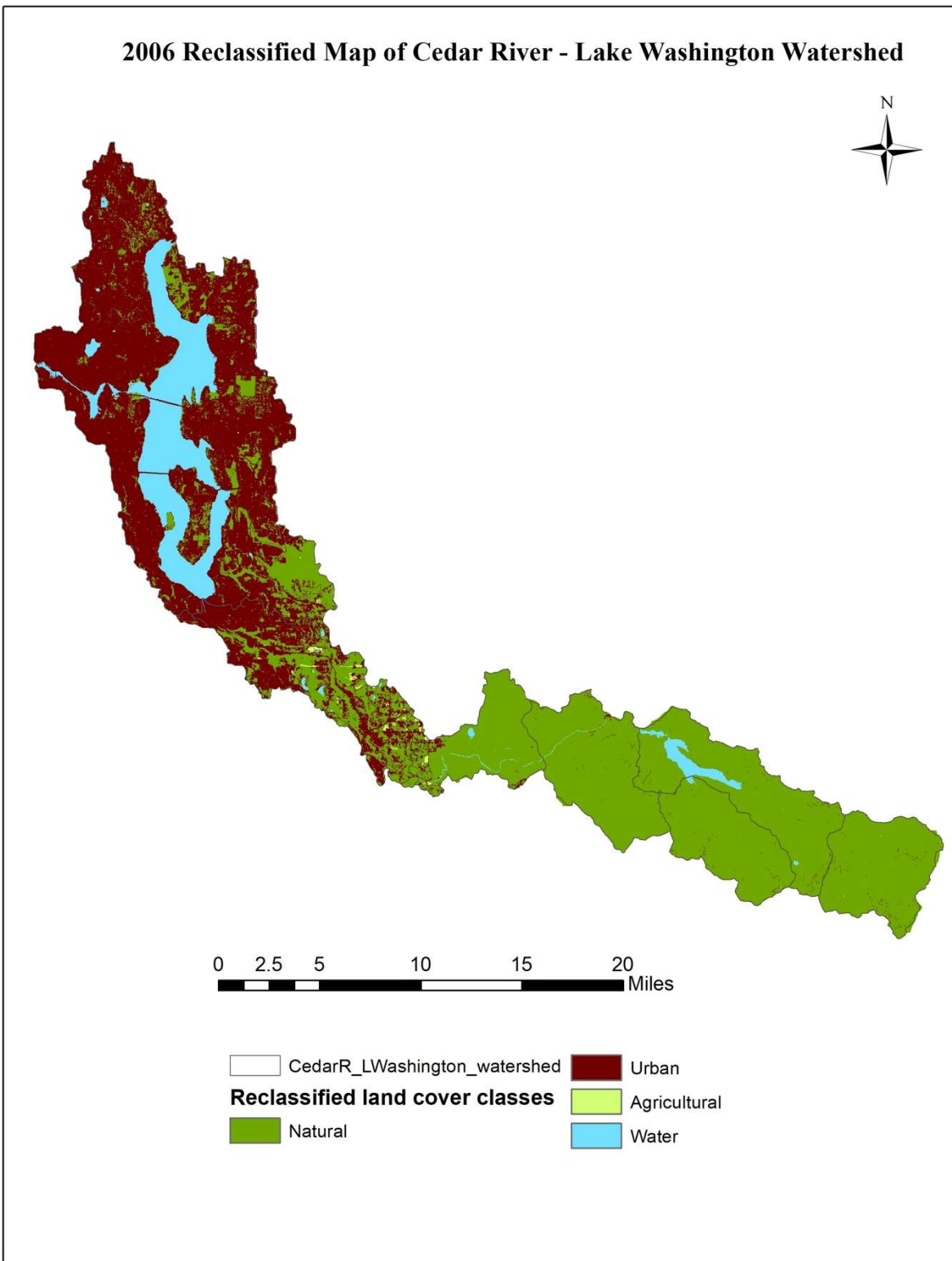
### 4.3.1 Sources of Land Cover Data

For this study, I obtained land cover maps from the official NOAA website (NOAA, 2022). Under the Coastal Change Analysis Program (C-CAP), the Office of Coastal Management (OCM), NOAA “produces national standardized land cover and change products for the coastal regions of the U.S.” (OCM, 2021). As briefed in the website, these maps are developed using Landsat Thematic Mapper imagery, with a 30m spatial resolution that tracks spatial landscape transformations and produces these maps every 5 years since 1992. For this study, I have used the maps for three years at a gap of 10 years - 1996, 2006, and 2016, in order to evaluate the land transformation in riparian landscapes over 20 years. As the NOAA maps had classified different land cover types into more precise classifications and consist of more than 20 land cover types, for this study, I reclassified the maps using four broad classifications: Urban, Agricultural, Natural and Water. With the help of ArcGIS 10.7.1 software, I reclassified NOAA maps for three years - 1996, 2006, and 2016.

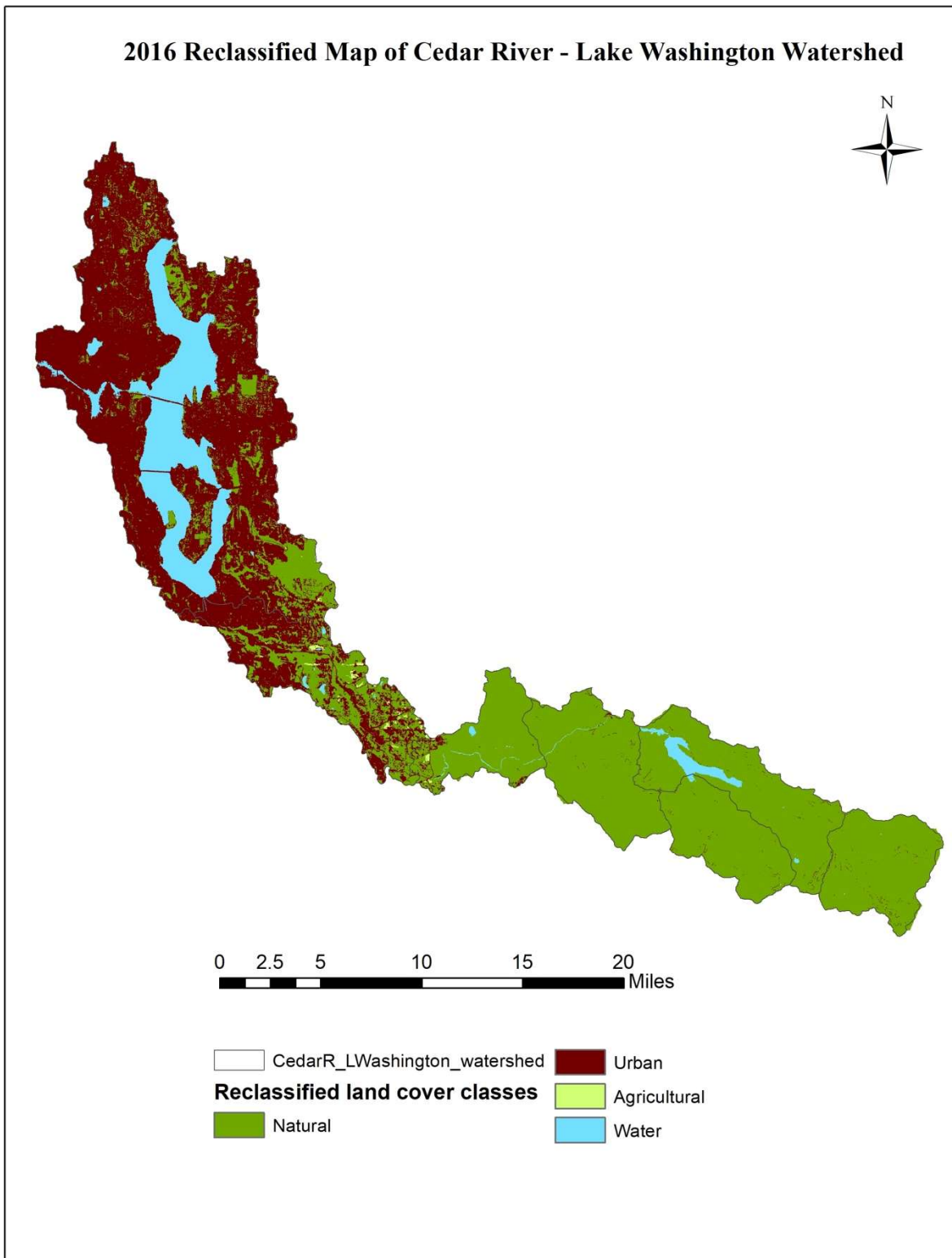
Below are the three reclassified maps for the study area watershed extracted from the NOAA maps for the study area watershed corresponding to the years 1996, 2006, and 2016 respectively.



Map 1 Reclassified map of study area watershed for 1996



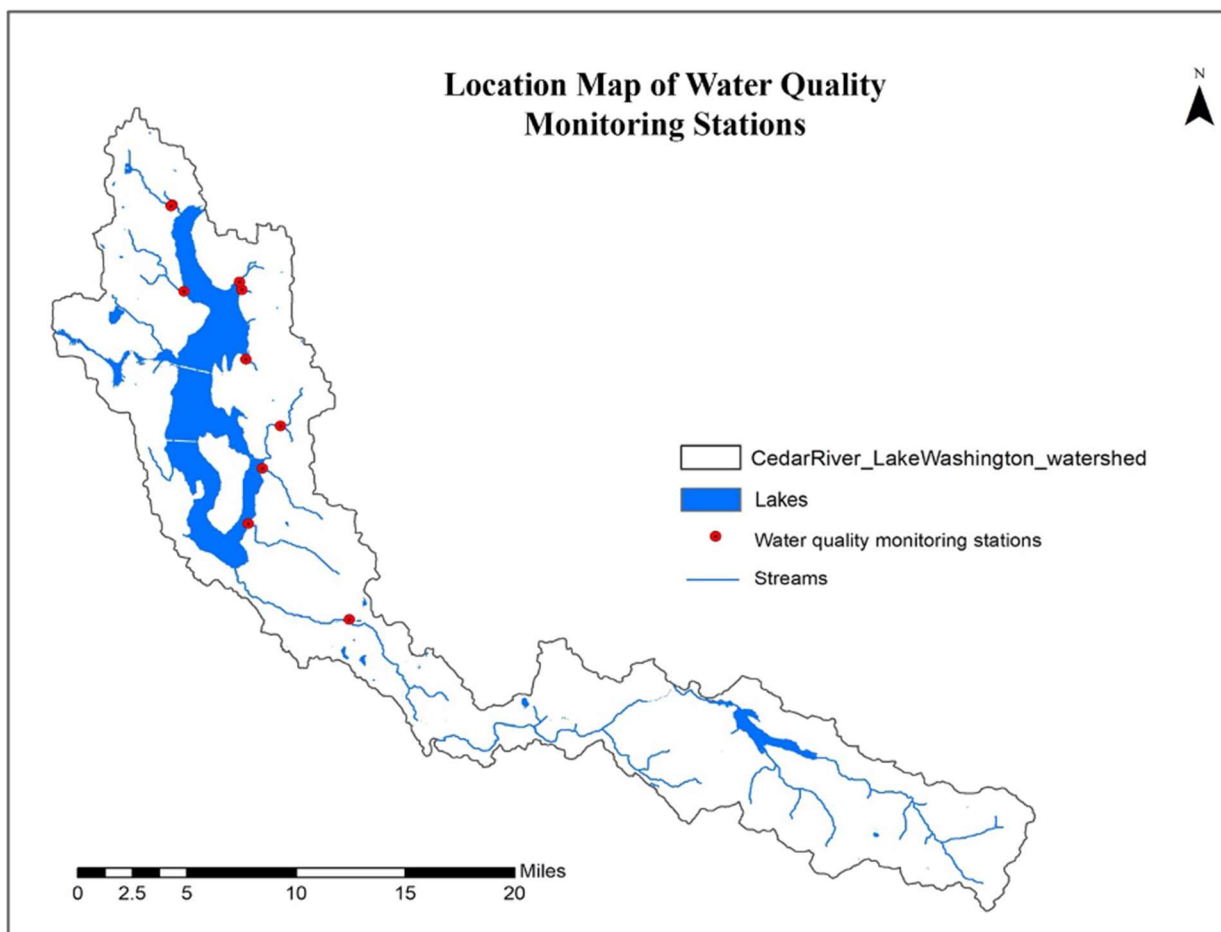
Map 2 Reclassified map of study area watershed for 2006



Map 3 Reclassified map of study area watershed for 2016

#### 4.3.2 Sources of Water Quality Data

For my study area, I have considered 10 water pollution monitoring stations within my study area watershed. Although there are more than 10 stations set up by the King County Department in the watershed, I have selected only those stations which contained monthly water pollution data for all the 3 years analyzed for this study as it corresponded to the years for which land cover data was also procured. The location of 9 stations out of 10 is on the small streams located on the periphery of Lake Washington; only one is located on the downstream of the Cedar River.



Map 4 Location of the monitoring stations in the study area watershed

### 4.3.3 Data Dictionary

Below is the data dictionary table that shows the different datasets used for this study along with the name of their source agencies / departments, and their primary use in the analysis.

Table 1 Data Dictionary

<b>Dataset</b>	<b>Source</b>	<b>Primary Use</b>
WA county boundaries	Washington Department of Natural Resources	Used to demarcate the King County in the base map
WRIA 8 and its sub-basins	Washington State Department of Ecology	Used for delineation of study area watershed
C-CAP regional land cover 1996, 2006, 2016	OCM, NOAA	Used to procure spatial data regarding natural, undisturbed riparian land structure
30m elevation SRTM data	USGS earth explorer	Used for making DEMs that help to delineate stream networks in the watershed.
Water quality monitoring stations	King County	Used to obtain local riparian buffers for the analysis
Water quality data 1996, 2006, 2016	King County	Used as dependent variables to test the research hypotheses.

## 4.4 Data Processing

In order to perform the spatial and statistical analyses for this study, I, further processed the raw data that was available from various secondary sources, as indicated in Table 1. This included processing both land cover as well as water quality data.

### 4.4.1 Delineation of Riparian Buffers

After I reclassified the study area watershed, in order to explore effects of riparian landscapes on surface water quality, I used two riparian scales for this study, 100 meters and 300 meters riparian buffers. Using 30m digital elevation models (DEMs) in Hydrology toolset under

Spatial Analyst Tools in ArcGIS 10.7.1 (ESRI), firstly, I delineated the stream network in the study area. Secondly, I measured a distance of 1km upstream as the buffer extent of the stream. Lastly, local riparian buffers were defined by buffering 100m, and 300m along the 1km stream stretch from the monitoring stations downstream. After delineating the buffers, I extracted reclassified raster imageries for each station at both 100m and 300m scale for the three years evaluated in the study.

#### *4.4.2 Processing Water Quality Data*

I obtained the water quality data used in this study from King County, Washington online portal, where, under the Major Lake and Stream Monitoring program, they collect periodical samples and record the values for various water quality parameters once or twice a month. In order to maintain uniformity of the data procured from the website, I only downloaded the required water quality for the four summer months, May, June, July, and August for the three years, 1996, 2006, and 2016 for each of the 10 stations. The downloaded data was transferred into excel sheets to obtain geometric mean values for each year. Appendix A contains 11 tables – 10 tables for each station with their downloaded values and the calculated geometric means for each water quality parameter, and one aggregate table which contains the values obtained from the 10 stations; this table is used for further analyses in this study.

### **4.5 Data Analysis**

After processing the raw data, I used a landscape analysis approach to quantify riparian landscape patterns in terms of land cover composition and landscape configuration. While I extracted data for riparian land cover composition from the reclassified raster imageries obtained from delineation of riparian buffers, to quantify landscape configuration, I used landscape metrics,

Aggregation Index (AI). The % of land composition for each land cover for each station along with their respective AIs at both 100m and 300m are given in Appendix B. I, then, used these spatial data along with processed water quality data to perform the following analyses to find answers to my research questions posed in Chapter 1.

#### *4.5.1 Trend Analysis*

In order to answer Research Questions 1 and 2 for this study, I performed a trend analysis separately on land cover as well as water quality data.

The first question in this thesis is: **How have the riparian landscape patterns in the Cedar River – Lake Washington watershed changed between 1996-2016?**

There are two parts to this question. The first part analyzes the change in land cover composition and the second part analyzes the changes landscape configuration (AI) for the 10 stations at two spatial scales of riparian buffer, 100m and 300m. In order to calculate the % change, I have considered 3 time periods – 1996-2006, 2006-2016, and 1996-2016.

##### *a) Changes in Riparian Landscape pattern*

- Land cover composition – After delineating and generating raster imageries for three different buffer widths around each of the 10 stations, I extracted land cover information for each of the reclassified land cover class using RECLASSIFY function in ArcGIS. I, then transferred the results to an Excel sheet to calculate the percentage change in each class for the two buffer zones - 100m, and 300m. The final results show how the land cover at each monitoring station has changed between the 3 time periods – 1996-2006, 2006-2016, and 1996-2016. The results indicate either positive or negative change in a land cover class over 20 years within two buffer boundaries.

The reclassified land cover categorization used for this study uses similar categorization as per the Regional Land Cover Classification Scheme (NOAA, 2021a):

1. Urban; it consists of 4 land covers - High Intensity Development (HID), Medium Intensity Development (MID), Low Intensity Development (LID), and Developed Open Spaces.
  2. Agricultural; it consists of Cultivated land and Pasture/hay land cover classes.
  3. Natural; it consists of all types of Forests - deciduous, evergreen and mixed forests land cover classes, all types of Palustrine wetlands - Palustrine Forested Wetlands (PFW), Palustrine Shrub Wetlands (PSW), and Palustrine Emergent Wetlands (PEW) land cover classes, along with Scrub/ Shrub land and Grassland covers.
  4. Water; it consists of water, unconsolidated shore, bare land, and aquatic beds land class.
- Landscape configuration – I transferred the delineated raster images as TIFF files into Frags tats in order to evaluate the configuration of different land cover types within variable buffer widths. For this study, I have used Aggregation Index (AI) as landscape metrics to study the changes in landscape configuration. AI represents class-level metrics and calculates how aggregated or disaggregated a particular land cover type is within the selected riparian buffer; it varies between 0 and 1, where 0 indicates the class is completely disaggregated and 1 indicates maximum aggregation, i.e., the class is highly clustered (He, Dezonias, & Mladenoff, 2000). The calculated AIs for the two buffer widths are given in Appendix B. After data analysis in Frags tats, I transferred the results into Excel to calculate the percentage change in AI for different land covers for the two buffer zones - 100m, and 300m for three years 1996, 2006, and 2016.

### *b) Changes in Water Quality*

The second question for the study is: **What changes in water quality have occurred in streams and rivers within the watershed between 1996 and 2016?**

In order to answer this question, I conducted a change analysis on the water quality data processed for the ten different stations in the study area watershed as shown in Appendix A. To calculate the change in water quality, I transferred the processed water quality data for the three years – 1996, 2006, and 2016 into an Excel sheet to calculate the percentage change in each parameter for each station for every 10 years (1996-2006, 2006-2016), and also for an overall 20 year time period (1996-2016). The final results show how the water quality at every monitoring station has changed between the evaluated time periods. It also suggests which of the evaluated 7 water quality parameters is the most affected in those time periods.

#### *4.5.2 Correlation Analysis*

The third question for the study is: **How are the two components of the riparian landscape pattern (composition and configuration) related to the different water quality parameters of streams and rivers in the Cedar river - Lake Washington watershed between 1996 and 2016?**

To determine the relationship between riparian landscape patterns and water quality parameters, I performed a correlation analysis using the CORREL function in Microsoft Excel between the two components of the riparian landscape pattern and water quality parameters for two different buffer widths. This function returns the Pearson's correlation coefficient (r) for two compared cell ranges. The equation used by the function to calculate the correlation coefficient is as follows:

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

where  $\bar{x}$  and  $\bar{y}$  are the sample means AVERAGE (array1) and AVERAGE (array2) (Microsoft, 2022). The coefficient value (r) indicates the strength of the linear relationship between a pair of variables (in this case the variables being riparian landscape patterns and water quality parameters). This value ranges between -1 and +1, where -1 indicates a complete negative correlation, +1 indicates a complete positive correlation, and 0 indicates no relation between the compared variables. A negative correlation indicates inverse relationship between the two variables, and a positive correlation indicates that both variable are directly related to one another, i.e., if one variable increases, the other variable also increases, and vice-versa. As absolute values are idealistic in nature, the closer a value is to -1 indicates a negative correlation, the closer a value is to +1 indicates a positive correlation, and the closer the value is to 0 indicates no relation between the variables.

For this study, I have categorized the correlation into 3 categories:

- Strong correlation (r between +/- 0.50 and +/- 1)
- Medium correlation (r between +/- 0.30 and +/- 0.50)
- Weak correlation between (r <= 0.30)

#### 4.5.3 Regression Analysis

The last question in this study is: **How significant are riparian landscape pattern in predicting the future trends of different physical and chemical parameters of water quality of streams and rivers in the Cedar river - Lake Washington watershed?**

In order to determine the significance of the impact of the two components of riparian landscape pattern on water quality parameters, I used multiple linear regression analysis. For this,

I used the 'Regression' function under Data Analysis in Microsoft Excel software. The purpose of this analysis is to determine the significance of the affect between a dependent variable and an independent variable. A dependent variable is the outcome variable that we are trying to predict, while an independent variable is the predictor variable which we use to predict the dependent variable. There are a total of five independent variables, including constant in this study; however the analysis uses only two riparian landscape components, % Natural and AI Urban as the two independent variables. The reason for selecting these two variables is that that they also showcased stronger correlation with few water quality parameters. Another variable is the Intercept variable or the Constant. It usually shows the impacts of other external variables which are not considered in the analysis.

The analysis provides a resultant regression output comprising of three major parts: the first part is the regression statistics that shows how well the calculated linear regression equation fits the source data; it comprises of  $r^2$  values varying between 0 to 1; the closer it is to 1, the better the model fits.  $r^2$  is a statistical measure that represents the proportion of the variance for a dependent variable that is explained by an independent variable or variables in a regression model. The second part is the Hypothesis test or Analysis of Variance (ANOVA); one of the components of this table is the *Significance F* value which indicates the significance or the P-value of the model. The model can be significant at different levels of significance; different levels of significance considered for this study are:

- Significant at 0.05 level (i.e., P-value < 0.05 \*)
- Significant at 0.01 level (i.e., P-value < 0.01 \*\*)
- Significant at 0.001 level (i.e., P-value < 0.001 \*\*\*)

If P-value is greater than 0.05, it is advised to choose different independent variables as the selected variables are insignificant for the dependent variable. The third part is the Coefficient table. It comprises of P-values and coefficients for each independent variable in the analysis. P-values in this table indicate the statistical significance of the relationship between each independent variable and the dependent variable, and are measured at three different significance levels as explained above. Coefficients, in this table, represent the nature of these relationships (positive or negative) (Frost, 2020). Therefore, performing this analysis will help me in answering my last and final research question for this thesis.

## 5 RESULTS

### 5.1 Trends in Riparian Landscape Patterns

#### a) 100m riparian buffer:

The trend analysis for the two components of riparian landscape pattern for the 100m riparian buffer in the study area watershed produced the following results:

Table 2 Changes in riparian landscape pattern within 100m riparian buffer

Station_name	Time-period	Composition		Configuration	
		% change in Urban LC	% change in Natural LC	% change in AI <sub>Urban</sub>	% change in AI <sub>Natural</sub>
CedarRiver A438	1996-2006	3.61	7.78	0.50	0.23
	2006-2016	2.50	21.69	1.87	7.17
	1996-2016	6.02	12.22	2.38	7.41
May Creek 0440	1996-2006	2.16	11.11	1.02	7.26
	2006-2016	0.00	16.67	0.95	16.48
	1996-2016	2.16	7.41	1.97	10.42
Coal Creek 0442	1996-2006	0.51	15.38	0.23	43.20
	2006-2016	7.73	60.00	3.00	55.09
	1996-2016	7.18	53.85	3.24	35.69
Kelsey Creek 0444	1996-2006	3.80	1.92	7.26	5.73
	2006-2016	6.58	1.31	12.70	4.76
	1996-2016	2.53	0.64	4.52	0.69
Yarrow Creek A499	1996-2006	0.00	0.00	0.00	1.23
	2006-2016	2.56	0.00	2.73	1.66
	1996-2016	2.56	0.00	2.73	0.41
Forbes Creek 0456	1996-2006	4.55	5.59	5.13	1.73
	2006-2016	0.00	0.74	6.51	3.88
	1996-2016	4.55	4.90	11.31	2.08
Junaita Creek 0446	1996-2006	6.25	6.25	1.29	20.00
	2006-2016	5.88	23.53	1.31	2.78
	1996-2016	0.00	18.75	0.00	22.22
Lyon Creek 0430	1996-2006	2.78	1.18	2.91	4.04
	2006-2016	1.43	3.49	2.10	3.56
	1996-2016	4.17	4.71	4.95	0.63
McAleer Creek A432	1996-2006	2.29	2.04	2.39	3.13
	2006-2016	0.75	1.04	2.05	5.53
	1996-2016	3.05	1.02	0.29	2.23
Thornton Creek 0434	1996-2006	0.54	0.00	0.09	7.14
	2006-2016	3.26	4.17	1.14	1.47
	1996-2016	2.70	4.17	1.05	5.56

0 indicates no change in area; Red color indicates negative change in percentage area

- Land cover composition:
  - Within this width of riparian buffer, 7 out of 10 stations have undergone an overall reduction in the % of Natural land cover between 1996-2016.
  - Coal Creek station has experienced maximum reduction in Natural land cover within this buffer, and the reduction has happened in the time period 2006-2016; between 1996-2006, it experienced an increase in the total Natural land cover within this buffer.
  - Junaita Creek station has also experienced similar trends in the % of Natural land cover for the evaluated time periods as that of Coal Creek station.
  - On the other hand, within this width of riparian buffer, 6 out of 10 stations have undergone an increase in the % of Urban land cover between 1996-2016.
  - The maximum increase in this land cover is experienced within the riparian buffer of Coal Creek station.
  - Interestingly, two stations, Cedar River and Lyon Creek stations have experience reduction in the % of Urban land cover for all the three evaluated time periods. These are also the stations, where the % of Natural land cover has increased for the overall time period (1996-2016).
- Landscape configuration:
  - Within this width of riparian buffer, 5 out of 10 stations have experienced an increase in  $AI_{Urban}$ ; one station, Junaita Creek has undergone no change in  $AI_{Urban}$  and 4 other stations have experienced a decrease in  $AI_{Urban}$  for the overall time period evaluated between 1996-2016.

- Kelsey Creek station has experienced maximum increase in  $AI_{Urban}$ . While Forbes Creek station has experienced a maximum decrease in  $AI_{Urban}$  for the overall time period evaluated between 1996-2016.
- For May Creek, Forbes Creek and Lyon Creek stations,  $AI_{Urban}$  has reduced for all the three evaluated time periods between 1996-2016.
- For Cedar river and Coal Creek station,  $AI_{Urban}$  has increased for all the three evaluated time periods between 1996-2016.
- On the other hand, within this width of riparian buffer, 4 out of 10 stations have experienced a decrease in  $AI_{Natural}$ ; 6 other stations have experienced an increase in  $AI_{Natural}$  for the overall time period evaluated between 1996-2016.
- Coal Creek and Junaita Creek stations have experienced maximum decrease in  $AI_{Natural}$  for the overall time period evaluated between 1996-2016.
- Cedar River and Thornton Creek stations have experienced maximum increase in  $AI_{Natural}$  for the overall time period evaluated between 1996-2016.

*b) 300m riparian buffer:*

The trend analysis for the two components of riparian landscape pattern for the 300m riparian buffer in the study area watershed produced the following results:

Table 3 Changes in riparian landscape pattern within 300m riparian buffer

Station_name	Time-period	Composition		Configuration	
		% change in Urban LC	% change in Natural LC	% change in AI <sub>Urban</sub>	% change in AI <sub>Natural</sub>
CedarRiver A438	1996-2006	1.46	0.31	1.03	0.53
	2006-2016	2.48	3.73	0.01	0.02
	1996-2016	0.98	3.41	1.04	0.51
May Creek 0440	1996-2006	0.62	3.33	1.00	1.86
	2006-2016	0.41	6.45	0.15	3.10
	1996-2016	0.21	3.33	1.15	4.89
Coal Creek 0442	1996-2006	1.87	0.00	0.27	4.76
	2006-2016	0.84	13.51	1.20	17.30
	1996-2016	2.73	13.51	1.48	22.89
Kelsey Creek 0444	1996-2006	0.48	0.80	0.12	0.68
	2006-2016	21.63	9.86	8.12	2.35
	1996-2016	22.22	9.15	7.99	1.68
Yarrow Creek A499	1996-2006	1.39	0.27	1.11	0.75
	2006-2016	2.47	1.90	1.07	0.34
	1996-2016	1.05	1.63	0.06	1.08
Forbes Creek 0456	1996-2006	10.92	6.98	2.32	0.11
	2006-2016	0.79	5.41	2.16	0.56
	1996-2016	11.79	12.01	0.12	0.45
Junaita Creek 0446	1996-2006	0.96	20.00	0.61	26.45
	2006-2016	1.33	13.89	0.72	13.33
	1996-2016	2.31	31.11	1.34	36.26
Lyon Creek 0430	1996-2006	1.49	2.62	1.93	5.79
	2006-2016	1.08	2.04	0.92	5.56
	1996-2016	0.43	0.52	1.03	0.56
McAleeer Creek A432	1996-2006	1.17	0.76	1.83	0.47
	2006-2016	0.47	1.14	0.98	1.75
	1996-2016	0.70	1.91	0.87	1.27
Thornton Creek 0434	1996-2006	2.39	9.46	1.63	1.35
	2006-2016	0.00	0.00	0.00	0.00
	1996-2016	2.39	9.46	1.63	1.35

0 indicates no change in area; Red color indicates negative change in percentage area

- Land cover composition:
  - Within this width of riparian buffer also, the similar stations have undergone an overall reduction in the % of Natural land cover between 1996-2016, only exception being McAleeer Creek; the 300m riparian buffer for this station has undergone an overall increase in the % of Natural land cover by 1.91% between 1996-2016, but

the 100m riparian buffer for this station experienced a 1.02% reduction in its Natural land cover for the same time period.

- Junaita Creek station has experienced maximum reduction in Natural land cover within this buffer, and the reduction has happened in all the three evaluated time periods.
  - Forbes Creek station has also experienced similar trends in the % of Natural land cover for the evaluated time periods.
  - However, for Coal Creek station, there has been no change in the natural land cover between 1996-2006; but has reduced by 13.5% between 2006-2016.
  - On the other hand, within this width of riparian buffer, almost all the stations have undergone an increase in the % of Urban land cover for the overall time period between 1996-2016; Lyon Creek and McAleer Creek have experienced less than 1% reduction in this land cover for the overall time period.
  - The maximum increase in this land cover is experienced within the riparian buffer of Kelsey Creek station.
  - Forbes Creek station has also experienced similar trends in the % of Urban land cover for the evaluated time periods within the 300m buffer.
- Landscape configuration:
    - Within this width of riparian buffer, 5 out of 10 stations have experienced an increase in  $AI_{Urban}$ ; and 5 other stations have experienced a decrease in  $AI_{Urban}$  for the overall time period evaluated between 1996-2016.

- Kelsey Creek station has experienced maximum increase in  $AI_{Urban}$ . While May Creek station has experienced a maximum decrease in  $AI_{Urban}$  for the overall time period evaluated between 1996-2016.
- For Cedar River and May Creek stations,  $AI_{Urban}$  has reduced for all the three evaluated time periods between 1996-2016.
- For Coal Creek, Junaita Creek, and Thornton Creek stations,  $AI_{Urban}$  has increased for all the three evaluated time periods between 1996-2016.
- On the other hand, within this width of riparian buffer, 6 out of 10 stations have experienced a decrease in  $AI_{Natural}$ ; 4 other stations have experienced an increase in  $AI_{Natural}$  for the overall time period evaluated between 1996-2016.
- Junaita Creek station has experienced maximum decrease in  $AI_{Natural}$  for the overall time period evaluated between 1996-2016.
- Coal Creek station has experienced maximum increase in  $AI_{Natural}$  for the overall time period evaluated between 1996-2016.

## 5.2 Trends in Water Quality

The results of the 7 water quality parameters tested at 10 monitoring stations are explained below:

- The Fecal Coliform (FC) concentrations in the stream water has reduced considerably (around 40% - 90%) across all the stations in the evaluated time periods.
- While pH concentrations across the stations have changed, but have remained within 7 and 8; thus indicating that it has incurred minor changes within safe permissible limits.
- Similarly, Total Phosphorous (TP) has also increased across all stations, however at Forbes Creek station, the TP concentration has increased predominantly by 240% between 1996-

2016. The only stations that have incurred reduction in TP concentrations include Cedar River and Coal Creek stations.

- Temperature has also increased for most stations, except Yarrow, Forbes, and Junaita Creek stations.
- The Total Nitrogen (TN) concentrations water has decreased across all stations, except at Yarrow and Forbes Creek station.
- The nitrate-nitrite concentrations in stream water has decreased for all the stations.
- Ortho-phosphate concentrations have increased for 5 and decreased for the other 5 stations. Maximum increase in its concentration is experienced at Forbes Creek station (+42.35%); while maximum decrease in its concentration is experienced at Cedar River station (-58.86%).

The detailed results of the trend analysis for water quality parameters between 1996 and 2016 are shown in Appendix C.

### **5.3 Correlation between Riparian Landscape Patterns and Water Quality Parameters**

Below I have shown the results of the correlation analysis for 100m and 300m riparian buffers separately.

#### *a) Correlation between 100m riparian landscape pattern and water quality parameters:*

The correlation analysis between the two components of riparian landscape pattern for the 100m riparian buffer and the water quality parameters in the study area watershed produced the following results:

Table 4 Correlation between 100m riparian landscape pattern and water quality parameters

Correlation coefficients (r)							
	Fecal Coliform	pH	Total Phosphorus	Temperature	Total Nitrogen	Nitrate-Nitrite	Ortho Phosphate
% Urban	0.18	0.50	-0.30	0.08	0.10	0.13	-0.28
% Natural	-0.09	-0.46	0.46	-0.06	0.05	-0.01	0.47
AI Urban	0.02	0.63	-0.41	-0.27	0.44	0.53	-0.26
AI Natural	-0.15	-0.38	0.30	-0.14	0.26	0.24	0.37

In Table 4 above, 5 out of 7 water quality parameters have shown strong and medium correlation with the 100m riparian landscape patterns. Out of the four components, AI<sub>Urban</sub> is strongly correlated to two water quality parameters, pH and nitrate-nitrite, and has medium correlation with TP and TN. %Natural has medium correlation with pH, TP, and Ortho-phosphate parameters. As AI<sub>Urban</sub> and %Natural are the two riparian landscape pattern components within the 100 m riparian buffer that shows some correlation with the water quality parameters, for the regression analysis for 100m buffer later, I have used these 2 components as the independent variables.

*b) Correlation between 300m riparian landscape pattern and water quality parameters:*

The correlation analysis between the two components of riparian landscape pattern for the 300m riparian buffer and the water quality parameters in the study area watershed produced the following results:

Table 5 Correlation between 300m riparian landscape pattern and water quality parameters

Correlation coefficients (r)							
	Fecal Coliform	pH	Total Phosphorus	Temperature	Total Nitrogen	Nitrate-Nitrite	Ortho Phosphate
% Urban	0.24	0.48	-0.17	0.05	0.19	0.18	-0.16
% Natural	-0.18	-0.47	0.31	-0.04	-0.05	-0.08	0.34
AI Urban	0.16	0.53	-0.14	-0.11	0.39	0.40	-0.06
AI Natural	-0.29	-0.33	0.18	-0.12	0.03	0.03	0.19

In Table 5 above, only 2 water quality parameters have shown strong and medium correlation with the 300m riparian landscape patterns. Out of the four components, AI<sub>Urban</sub> is strongly correlated to pH, and has medium correlation with nitrate-nitrite. %Natural and % Urban has medium correlation with pH. For the 300m regression also, I have used AI<sub>Urban</sub> and %Natural as the independent variables (to maintain uniformity in the results).

#### **5.4 Significance of Riparian Landscape in Predicting Water Quality**

In order to assess the significance of the riparian landscape pattern in predicting water quality parameters, I conducted multiple regression analysis for 100m as well as 300m riparian buffers.

*a) Regression Analysis for assessing the significance of riparian landscape patterns in 100m buffer:*

For this buffer width, I took AI<sub>Urban</sub> and %Natural within 100m buffer as two independent variables, and 4 out of the 7 water quality parameters tested as 4 separate dependent variables, pH, TP, TN, and Nitrate-nitrite. These water quality parameters were selected as they show some degree of correlation (strong or medium) with the two selected riparian landscape pattern components, AI<sub>Urban</sub> and %Natural. However, the tested models for pH and TP did not show significance at the 0.001 level; their detailed outputs are shown in Appendix D. Therefore, here, I have shown the output results for TN and Nitrate-nitrite.

The regression analysis between the independent and dependent variables for TN and Nitrate-nitrite produced the following results:

## 1. Total nitrogen (TN)

Table 6 Summary Table for Total Nitrogen (TN) in 100m riparian buffer model

<b>Model Summary</b>					
Multiple R		0.6627			
R Square		0.4392			
Adjusted R Square		0.3976			
Standard Error		0.5104			
Observations		30			

<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	5.5079	2.7539	10.5713	0.000407 ***
Residual	27	7.0338	0.2605		
Total	29	12.5416			

<b>Coefficients</b>				
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-3.03698	0.93001	-3.26553	0.002968 **
% Natural	0.01808	0.00522	3.46443	0.001790 **
AI Urban	0.04661	0.01017	4.58430	0.000093 ***

\*\* P-value < 0.01; \*\*\* P-value < 0.001

Results from the summary Table 6 is interpreted as follows:

- R Square: 0.44. This indicates that 44% of the variation in the observed TN concentration between 1996-2016 can be explained by the %Natural and AI<sub>Urban</sub> in the 100m riparian buffer within the study area watershed.
- Significance F: 0.0004 (i.e. < 0.001). This indicates that the independent variables combined have a statistically significant association with the TN concentration in streams and rivers within the study area watershed.

- P-value of  $AI_{Urban}$  : 0.00009 (i.e.  $< 0.001$ ). This indicates that  $AI_{Urban}$  is a statistically significant predictor variable at 0.001 level for TN concentration in streams and rivers within the study area watershed.
- Co-efficient of  $AI_{Urban}$  : 0.05. This indicates that for every unit of increase in  $AI_{Urban}$  within the 100m riparian buffer, Total Nitrogen concentration in streams and rivers within the study area watershed increases by 0.05 units, assuming other independent variables remain constant.
- P-value of %Natural: 0.0017 (i.e.  $< 0.01$ ). This indicates that %Natural is a statistically significant predictor at 0.01 level significance for TN concentration in streams and rivers within the study area watershed.
- Co-efficient of  $AI_{Urban}$  : 0.02. This indicates that for every unit of increase in  $AI_{Urban}$  within the 100m riparian buffer, TN concentration in streams and rivers within the study area watershed increases by 0.02 units, assuming other independent variables remain constant.

## 2. Nitrate-nitrite

Table 7 Summary Table for Nitrate-nitrite in 100m riparian buffer model

<b>Model Summary</b>					
Multiple R		0.7319			
R Square		0.5357			
Adjusted R Square		0.5013			
Standard Error		0.4945			
Observations		30			

<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	7.6159	3.8079	15.5742	0.000032 ***
Residual	27	6.6015	0.2445		
Total	29	14.2174			

<b>Coefficients</b>				
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-3.92902	0.90098	-4.36082	0.000169 ***
% Natural	0.01956	0.00505	3.86924	0.000625 ***
AI Urban	0.05497	0.00985	5.58082	0.000006 ***

\*\*\* P-value < 0.001

Results from the summary Table 7 is interpreted as follows:

- R Square: 0.54. This indicates that 54% of the variation in the observed Nitrate-nitrite concentration between 1996-2016 can be explained by the %Natural and AI<sub>Urban</sub> in the 100m riparian buffer within the study area watershed.
- Significance F: 0.00003 (i.e. < 0.001). This indicates that the independent variables combined have a statistically significant association with the Nitrate-nitrite concentration in streams and rivers within the study area watershed.

- P-value of  $AI_{Urban}$  : 0.0000006 (i.e.  $< 0.001$ ). This indicates that  $AI_{Urban}$  is a statistically significant predictor at 0.001 level for Nitrate-nitrite concentration in streams and rivers within the study area watershed.
- Co-efficient of  $AI_{Urban}$  : 0.05. This indicates that for every unit of increase in  $AI_{Urban}$  within the 100m riparian buffer, Nitrate-nitrite concentration in streams and rivers within the study area watershed increases by 0.05 units, assuming other independent variables remain constant.
- P-value of %Natural: 0.0006 (i.e.  $< 0.001$ ). This indicates that %Natural is a statistically significant predictor at 0.001 level for Nitrate-nitrite concentration of water in streams and rivers within the study area watershed.
- Co-efficient of  $AI_{Urban}$  : 0.02. This indicates that for every unit of increase in  $AI_{Urban}$  within the 100m riparian buffer, Nitrate-nitrite concentration in streams and rivers within the study area watershed increases by 0.02 units, assuming other independent variables remain constant.

*b) Regression Analysis for assessing the significance of riparian landscape patterns in 300m buffer:*

Similar to the 100m buffer, for 300m buffer too, I took  $AI_{Urban}$  and %Natural within 300m buffer as two independent variables, and 5 out of the 7 water quality parameters tested as 5 separate dependent variables, pH, TP, TN, Nitrate-nitrite, and Ortho-phosphate. These water quality parameters were selected as they show some degree of correlation (strong or medium) with the two selected riparian landscape pattern components,  $AI_{Urban}$  and %Natural. However, the tested models for pH, TP, and Ortho-phosphate did not show significance at the 0.001 level; their detailed

outputs are shown in Appendix E. Therefore, here, I have shown the output results for TN and Nitrate-nitrite concentrations just like for 100m buffer; their model is significant at 0.001 level.

The regression analysis between the independent and dependent variables for TN and Nitrate-nitrite produced the following results:

1. Total nitrogen (TN)

Table 8 Summary Table for Total Nitrogen (TN) in 300m riparian buffer model

<b>Model Summary</b>					
Multiple R		0.6517			
R Square		0.4247			
Adjusted R Square		0.3821			
Standard Error		0.5169			
Observations		30			

<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	5.3265	2.6633	9.9664	0.000573 ***
Residual	27	7.2151	0.2672		
Total	29	12.5416			

<b>Coefficients</b>				
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-6.91299	1.84542	-3.74602	0.000863 ***
% Natural	0.02901	0.00811	3.57752	0.001338 **
AI Urban	0.08579	0.01928	4.44950	0.000134 ***

\*\* P-value < 0.01; \*\*\* P-value < 0.001

Results from the summary Table 8 is interpreted as follows:

- R Square: 0.42. This indicates that 42% of the variation in the observed TN concentration between 1996-2016 can be explained by the %Natural and AI<sub>Urban</sub> in the 100m riparian buffer within the study area watershed.

- Significance F: 0.0006 (i.e.  $< 0.001$ ). This indicates that the independent variables combined have a statistically significant association with the TN concentration in streams and rivers within the study area watershed.
- P-value of  $AI_{Urban}$  : 0.0001 (i.e.  $< 0.001$ ). This indicates that  $AI_{Urban}$  for 300m riparian buffer is a statistically significant predictor at 0.001 level for TN concentration in streams and rivers within the study area watershed.
- Co-efficient of  $AI_{Urban}$  : 0.09. This indicates that for every unit of increase in  $AI_{Urban}$  within the 100m riparian buffer, TN concentration in streams and rivers within the study area watershed increases by 0.09 units, assuming the other independent variables remain constant.
- P-value for %Natural: 0.0013 (i.e.,  $< 0.01$ ). This indicates that %Natural for 300m riparian buffer is a statistically significant predictor at 0.01 level for TN concentration of water in streams and rivers within the study area watershed.
- Co-efficient of %Natural: 0.03. This indicates that for every unit of increase in  $AI_{Urban}$  within the 100m riparian buffer, the TN concentration in streams and rivers within the study area watershed increases by 0.03 units, assuming the other independent variables remain constant.

## 2. Nitrate-nitrite

Table 9 Summary Table for Nitrate-nitrite in 300m riparian buffer model

<b>Model Summary</b>					
Multiple R		0.6345			
R Square		0.4026			
Adjusted R Square		0.3583			
Standard Error		0.5609			
Observations		30			

<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	5.7234	2.8617	9.0966	0.000955 ***
Residual	27	8.4940	0.3146		
Total	29	14.2174			

<b>Coefficients</b>				
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	-7.34778	2.00231	-3.66966	0.001053 **
% Natural	0.02922	0.00880	3.32099	0.002580 **
AI Urban	0.08859	0.02092	4.23500	0.000237 ***

\*\* P-value < 0.01; \*\*\* P-value < 0.001

Results from the summary Table 9 is interpreted as follows:

- R Square: 0.40. This indicates that 40% of the variation in the observed Nitrate-nitrite concentrations between 1996-2016 can be explained by the %Natural and AI<sub>Urban</sub> in the 300m riparian buffer within the study area watershed.
- Significance F: 0.0009 (i.e. < 0.001). This indicates that the independent variables combined have a statistical significant association with the Nitrate-nitrite concentration in streams and rivers within the study area watershed.

- P-value of  $AI_{Urban}$  : 0.0002 (i.e.  $< 0.001$ ). This indicates that  $AI_{Urban}$  for 300m riparian buffer is a statistically significant predictor at 0.001 level for Nitrate-nitrite concentration in streams and rivers within the study area watershed.
- Co-efficient of  $AI_{Urban}$  : 0.09. This indicates that for every unit of increase in  $AI_{Urban}$  within the 300m riparian buffer, Nitrate-nitrite concentration in streams and rivers within the study area watershed increases by 0.09 units, assuming the other independent variables remain constant.
- P-value for %Natural: 0.003 (i.e.,  $< 0.01$ ). This indicates that %Natural for 300m riparian buffer is a statistically significant predictor at 0.01 level for Nitrate-nitrite concentration in streams and rivers within the study area watershed.
- Co-efficient of %Natural: 0.03. This indicates that for every unit of increase in  $AI_{Urban}$  within the 100m riparian buffer, Nitrate-nitrite concentration in streams and rivers within the study area watershed increases by 0.03 units, assuming the other independent variables remain constant.

## 6 DISCUSSION

This chapter aims to explore the implications of the results presented in Chapter 5 through various statistical analyses, and discuss the significance of these findings for future research concerning riparian zones and water quality management in the study area watershed. This thesis set out to answer the overarching question: **How do landscape patterns in the riparian zone affect the physical and chemical parameters of water quality in the Cedar River – Lake Washington watershed?**

The results of the analysis show landscape patterns of both urban and natural land cover within the riparian explain the variability of water quality properties of rivers and streams of the Cedar River – Lake Washington watershed.

The trend analysis from this study indicates that natural as well as urban land covers, within different widths of riparian buffers for most of the monitoring stations have undergone significant changes between 1996 and 2016. The land cover pattern has changed both in composition and configuration. Along with the riparian land covers, the change in physical and chemical parameters of water quality show that while some water quality parameters have improved, others have worsened over the 20 year time frame. FC and nitrate-nitrite concentrations have decreased for all the stations assessed within the study area watershed. TN concentration has also decreased for most of the stations within the study area watershed, except at Yarrow and Forbes Creek station. This indicates that water quality with respect to these parameters have improved between 1996-2016. The pH and Temperature have also changed for all the stations for the evaluated time periods. On the other hand, TP concentration has increased for most of the stations. Orthophosphate concentrations have increased for some of the stations and decreased for the other. An

increase in the TP and Ortho-phosphate concentrations indicate that with respect to these parameters, water quality in the study area watershed has deteriorated over time.

Although the trend analysis for riparian landscape pattern and water quality parameters indicate that both these variables have experienced substantial changes, the results of the correlation matrix indicate that the riparian landscape components are strongly correlated (Pearson's correlation coefficient ( $r$ )  $\geq \pm 0.5$ ) to only a few water quality parameters. Moreover,  $AI_{Urban}$  (configuration) and %Natural (composition) are the two riparian landscape pattern components that show some degree of correlation, both within 100m as well as 300m riparian buffer. The other two components,  $AI_{Natural}$  and % Urban are not strongly correlated to most of the tested water quality parameters.

The results of multi-regression models show that the riparian landscape pattern play a key role in explaining the concentrations TN and Nitrate-nitrite in the Cedar River – Lake Washington watershed. Specifically two variables ( $AI_{Urban}$  and %Natural) measured within the 100m and 300m buffer width are significant in explaining TN and Nitrate-nitrite concentration in river and streams within the study area watershed. Consistent with recent studies that explore multiple scale effects of landscape patterns on water quality in other basins (Song et al., 2021; Xiao, Wang, Zhang, & Zhang, 2016; Xu et al., 2023), these results indicate the need to consider the riparian landscape patterns at multiple scales in defining strategies to protect water quality.

## 7 CONCLUSION

This thesis explores the Cedar river-Lake Washington watershed, with the intent of identifying the spatial and temporal relationships between riparian landscape patterns and selected physical and chemical parameters, thereby allowing the prediction of water quality trends. The analysis shows that there is a link between the spatial and temporal patterns of the riparian landscape within 100m and 300m buffer widths, and a few physical and chemical parameters of water quality. Specifically, there is a significant relationship between the composition and configuration of the riparian landscape and Total Nitrogen and Nitrate-nitrite concentrations.

This study provides evidence that both the riparian landscape composition and configuration within the 100m and 300m buffer width play an important role in protecting stream and river water quality and should be considered in developing comprehensive plans. The current Comprehensive Plans documented by all the cities in the study area watershed, including the cities of Seattle, Bellevue, Kirkland, and Renton have included policy guidelines regarding the protection of natural, undisturbed land covers along all the riparian corridors, and limiting development within them “to protect the natural functions and values of these areas” (Seattle\_OPCD, 2016). As the findings of this study are for the time period 1996-2016, the impacts of the current policies are not assessed within this study. However, based on the findings of this study, I propose the following recommendations to improve the current guidelines:

- 1) Within the planning documents, the width of the riparian buffer to be allocated as riparian corridor should be specified and include strategies to maintain riparian vegetation within both 100m and 300m buffer widths.
- 2) Along with limiting development within the riparian corridors, the Comprehensive Plans should also include a clause regarding the importance of compact or aggregated urban

development within the riparian corridors in order to regulate and maintain both Total Nitrogen and Nitrate-nitrite concentrations in the waters of streams and rivers within the study area watershed.

- 3) The trend analysis for the water quality parameters also suggests that over the evaluated time periods, concentrations of Total phosphorous (TP) in waters of most of the stations show an increasing trend in the stream and river water within the study area watershed. As neither of the regression models at 100m or 300m for TP show significance at 0.001 level future water quality assessment with respect to TP concentrations will require considering other spatial scales like basin and sub-basin scales for water quality assessment. Along with TP, FC, pH, Temp, and Ortho-phosphate concentrations also need to be assessed at other spatial scales.

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## APPENDIX A

Each table below represents the downloaded data for each parameter along with their geometric means for each of the three time periods:

Appendix Table A. 1 Cedar River Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
Cedar River Station	1996	5/14/96	No	66	7.82	0.017	11.2	0.397	0.305	0.009
		6/11/96	No	14	7.38	0.015	12.5	0.254	0.201	0.009
		7/16/96	No	28	7.27	0.01	14.8	0.227	0.146	0.007
		8/13/96	No	14	7.68	0.009	18.6	0.266	0.21	0.014
	GM			24.53	7.53	0.01	14.01	0.28	0.21	0.01
	2006	5/10/06	No	5	7.5	0.0150	10	0.251	0.222	0.0037
		6/14/06	No	42	7.2	0.0154	12.1	0.256	0.222	0.004
		7/12/06	No	42	7.6	0.0139	13.3	0.216	0.162	0.004
		8/16/06	No	13	7.3	0.0215	14.3	0.183	0.213	0.0062
	GM			18.40	7.40	0.02	12.32	0.22	0.20	0.00
	2016	5/11/16	No	2	7.53	0.0102	14.4	0.225	0.169	0.0039
		6/15/16	No	5	7.7	0.0115	13.5	0.211	0.149	0.0036
		7/13/16	No	22	7.62	0.0136	14.9	0.216	0.149	0.0036
		8/10/16	No	5	7.7	0.0117	16.5	0.203	0.142	0.0045
	GM			5.76	7.64	0.01	14.79	0.21	0.15	0.00

Appendix Table A. 2 May Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
May Creek	1996	5/14/96	No	450	7.56	0.058	12.5	1.04	0.728	0.018
		6/11/96	No	57	7.63	0.041	12.7	1.44	1.26	0.024
		7/16/96	No	150	7.58	0.083	14.3	1.71	1.68	0.035
		7/16/96	No	160	7.53	0.055	14.3	1.67	1.66	0.044
		8/13/96	No	80	7.62	0.054	14.8	1.83	1.71	0.047
	GM			137.56	7.58	0.06	13.69	1.51	1.34	0.03
	2006	5/10/06	No	26	7.7	0.0488	11	1.44	1.19	0.0216
		6/14/06	No	430	7.8	0.0681	13.7	1.24	0.84	0.024
		7/12/06	No	260	7.6	0.0637	14.1	1.48	1.33	0.0311
		8/16/06	No	120	8.2	0.0741	14.2	1.54	1.51	0.0367
		8/16/06	No	130	8.2	0.0742	14.2	1.57	1.52	0.0381
	GM			135.30	7.90	0.07	13.38	1.45	1.25	0.03
	2016	5/11/16	No	57	7.78	0.0655	14.6	1.44	1.14	0.0328
		6/15/16	No	50	7.97	0.0550	13.4	1.42	1.28	0.0331
		7/13/16	No	76	7.98	0.0820	15.5	1.52	1.32	0.0338
		8/10/16	No	50	8	0.0584	15.8	1.39	1.25	0.0357
	GM			57.37	7.93	0.06	14.79	1.44	1.25	0.03

Appendix Table A. 3 Coal Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
Coal Creek	1996	5/14/96	No	150	7.82	0.039	11.3	1.06	0.995	0.016
		6/11/96	No	140	8.05	0.026	12	0.518	0.448	0.014
		6/11/96	No	170	8.13	0.023	12	0.575	0.472	0.013
		7/16/96	No	110	7.88	0.042	13.9	0.37	0.3	0.024
		8/13/96	No	110	8.15	0.044	15	0.423	0.26	0.031
	GM			134.00	8.00	0.03	12.77	0.55	0.44	0.02
	2006	5/10/06	No	56	8.2	0.0227	10.4	0.711	0.6	0.0084
		6/14/06	No	290	8.1	0.0469	13.5	0.822	0.678	0.0165
		7/12/06	No	310	8.1	0.0366	14.4	0.389	0.313	0.0157
		8/16/06	No	56	8.4	0.0447	14.6	0.229	0.214	0.0177
	GM			129.58	8.20	0.04	13.11	0.48	0.41	0.01
	2016	5/11/16	No	45	8.23	0.0288	12	0.502	0.374	0.0139
		6/15/16	No	83	8.3	0.0251	11.5	0.358	0.263	0.0119
		7/13/16	No	60	8.33	0.0472	14.1	0.395	0.226	0.016
		8/10/16	No	32	8.36	0.0236	15	0.293	0.177	0.0126
	GM			51.75	8.30	0.03	13.07	0.38	0.25	0.01

Appendix Table A. 4 Kelsey Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
Kelsey Creek	1996	5/14/96	No	310	7.08	0.0980	12.7	0.81	0.508	0.053
		6/11/96	No	500	7.22	0.0830	13.4	0.829	0.598	0.051
		7/16/96	No	210	6.8	0.1220	16.6	0.727	0.526	0.061
		8/13/96	No	280	7.28	0.0990	15.7	0.703	0.513	0.067
	GM			308.98	7.09	0.10	14.51	0.77	0.54	0.06
	2006	5/10/06	No	60	7.5	0.0940	11.4	0.79	0.515	0.0485
		6/14/06	No	120	7.6	0.1136	15.5	0.736	0.413	0.0604
		7/12/06	No	160	7.3	0.1262	16	0.646	0.404	0.0665
		8/16/06	No	220	8.2	0.1325	16.2	0.584	0.432	0.0701
	GM			126.17	7.64	0.12	14.63	0.68	0.44	0.06
	2016	5/10/16	No	40	7.38	0.1169	13.7	0.454	0.194	0.0543
		6/14/16	No	50	7.34	0.1338	14.2	0.43	0.142	0.0619
		7/12/16	No	23	7.37	0.1262	17	0.313	0.0719	0.0594
		8/9/16	No	25	7.32	0.1691	16.1	0.366	0.0577	0.0574
	GM			32.75	7.35	0.14	15.19	0.39	0.10	0.06

Appendix Table A. 5 Yarrow Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
Yarrow Creek	1996	5/15/96	No	53	8.12	0.056	11.6	2.28	2.17	0.051
		6/10/96	No	170	7.66	0.078	11.6	2.31	2.2	0.056
		7/15/96	No	220	8	0.086	14.1	2.34	2.29	0.058
		8/12/96	No	26	8.04	0.076	13.2	2.26	4.54	0.055
	GM			84.73	7.95	0.07	12.58	2.30	2.65	0.05
	2006	5/8/06	No	41	8	0.09	10.4	2.52	2.45	0.0446
		6/12/06	No	130	7.9	0.10	14	2.69	2.47	0.0507
		7/10/06	No	91	7.8	0.10	11.8	2.61	2.51	0.0525
		8/14/06	No		8	0.09	12.6	2.41	2.51	0.0497
	GM			78.57	7.92	0.09	12.13	2.56	2.48	0.05
	2016	5/10/16	No	69	8.04	0.0891	11.8	2.41	2.39	0.0511
		6/14/16	No	63	8.07	0.0770	11.4	2.39	2.34	0.0501
		7/12/16	No	33	7.99	0.0742	12.4	3.3	2.27	0.0468
		8/9/16	No	16	7.95	0.0761	12.2	2.29	2.25	0.0483
	GM			38.92	8.01	0.08	11.94	2.57	2.31	0.05

Appendix Table A. 6 Forbes Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
Forbes Creek	1996	5/15/96	No	2500	7.56	0.07	12.8	0.958	0.639	0.044
		5/15/96	No	900	7.66	0.066	12.7	0.954	0.645	0.045
		6/10/96	No	410	7.38	0.094	13.3	0.871	0.611	0.059
		7/15/96	No	1300	7.58	0.126	17.3	0.689	0.507	0.077
		8/12/96	No	380	7.61	0.104	15.5	0.786	0.54	0.065
	GM			854.55	7.56	0.09	14.21	0.85	0.59	0.06
	2006	5/8/06	No	68	7.4	0.1044	11.1	0.902	0.602	0.0461
		6/12/06	No	240	7.1	0.1426	14.8	0.976	0.508	0.0697
		7/10/06	No	100	7	0.1628	16.2	0.689	0.282	0.0724
		8/14/06	No	170	7.3	0.1527	15.7	0.605	0.274	0.0575
	GM			129.06	7.20	0.14	14.30	0.78	0.39	0.06
	2016	5/11/16	No	41	7.02	0.4568	11.9	1.3	0.315	0.0681
		6/15/16	No	60	6.4	0.3786	12.5	1.08	0.014	0.189
		7/13/16	No	8	7.12	0.2436	15.4	1.09	0.263	0.0454
		8/10/16	No	160	7.59	0.2032	16	0.758	0.329	0.0725
	GM			42.12	7.02	0.30	13.84	1.04	0.14	0.08

Appendix Table A. 7 Junaita Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
Junaita Creek	1996	5/15/96	No	160	7.59	0.042	13.6	1.46	1.21	0.023
		6/10/96	No	260	7.39	0.042	13.7	1.9	1.76	0.029
		7/15/96	No	280	7.58	0.072	18.2	2.11	1.82	0.036
		8/12/96	No	350	7.67	0.057	16.2	1.88	1.86	0.036
	GM			252.69	7.56	0.05	15.31	1.82	1.64	0.03
	2006	5/8/06	No	390	7.7	0.0835	11.1	1.64	1.41	0.0435
		6/12/06	No	330	7.5	0.1243	14.1	1.55	1.16	0.0743
		7/10/06	No	280	7.5	0.1502	14.6	1.47	1.21	0.104
		8/14/06	No	320	7.8	0.1767	15	1.34	1.1	0.118
	GM			327.70	7.62	0.13	13.61	1.50	1.21	0.08
	2016	5/11/16	No	180	7.53	0.0695	13.6	1.46	1.25	0.0346
		6/15/16	No	80	7.52	0.0704	12.7	1.36	1.19	0.0357
		7/13/16	No	130	7.27	0.0824	15.7	1.27	1.06	0.0364
		8/10/16	No	200	7.62	0.0716	15.8	1.29	1.17	0.0384
	GM			139.10	7.48	0.07	14.39	1.34	1.17	0.04

Appendix Table A. 8 Lyon Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
Lyon Creek	1996	5/15/96	No	300	7.77	0.037	12	1.29	1.16	0.022
		6/10/96	No	270	7.78	0.049	12.5	1.31	1.24	0.033
		6/10/96	No	320	7.71	0.044	12.5	1.39	1.24	0.029
		7/15/96	No	250	7.66	0.078	17.1	1.43	1.25	0.043
		8/12/96	No	420	7.65	0.062	15.3	1.29	1.17	0.042
		8/12/96	No	370	7.68	0.062	15.3	1.25	1.18	0.041
	GM			316.60	7.71	0.05	13.99	1.33	1.21	0.03
	2006	5/8/06	No	320	7.6	0.0604	9.5	1.34	1.03	0.0181
		5/8/06	No	460	7.6	0.0599	9.5	1.37	1.03	0.0177
		6/12/06	No	1200	7.5	0.0881	13.4	1.49	1.14	0.0338
		7/10/06	No	330	7.5	0.0814	14.5	1.38	1.2	0.0425
		7/10/06	No	360	7.5	0.0813	14.5	1.39	1.19	0.0422
		8/14/06	No	250	7.8	0.0842	14.1	1.21	1.09	0.038
	GM			416.84	7.58	0.07	12.37	1.36	1.11	0.03
	2016	5/11/16	No	19	7.85	0.0598188	15.2	1.2	1	0.0301
		6/15/16	No	560	7.61	0.064362	13.2	1.2	0.943	0.0284
		7/13/16	No	63	7.87	0.0672646	16.6	1.06	0.884	0.0354
		8/10/16	No	130	7.89	0.0651192	16.7	0.976	0.864	0.0362
	GM			96.62	7.80	0.06	15.36	1.10	0.92	0.03

Appendix Table A. 9 McAleer Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
McAleer Creek	1996	5/15/96	No	200	7.86	0.042	12.9	1.32	1.06	0.019
		6/10/96	No	450	7.55	0.066	12.3	1.8	1.66	0.04
		7/15/96	No	320	7.86	0.099	15.5	1.97	1.83	0.041
		8/12/96	No	250	7.88	0.098	13.8	1.92	1.83	0.061
	GM			291.30	7.79	0.07	13.57	1.73	1.56	0.04
	2006	5/8/06	No	270	7.8	0.0772	9.8	1.74	1.47	0.0245
		6/12/06	No	360	7.7	0.0844	14.4	1.56	1.23	0.0303
		6/12/06	No	430	7.7	0.0829	14.4	1.52	1.23	0.0309
		7/10/06	No	250	7.7	0.0996	13.9	2.12	1.9	0.0499
		8/14/06	No	310	7.9	0.1040	13.2	1.98	1.91	0.0481
	GM			317.75	7.76	0.09	13.01	1.77	1.52	0.04
	2016	5/11/16	No	50	7.8	0.0806	14.5	1.69	1.43	0.0356
		6/15/16	No	270	7.81	0.0747	12.7	1.52	1.28	0.0327
		7/13/16	No	82	7.89	0.0751	15	1.82	1.6	0.0388
		8/10/16	No	510	7.87	0.0734	15.1	1.71	1.57	0.0386
	GM			154.15	7.84	0.08	14.29	1.68	1.46	0.04

Appendix Table A. 10 Thornton Creek Station

Locator	Year	Date	storm	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
Thornton Creek	1996	5/15/96	No	390	7.73	0.047	12.1	1.45	1.26	0.03
		6/10/96	No	690	7.66	0.069	12.6	1.54	1.38	0.042
		7/15/96	No	2000	7.78	0.096	17.3	1.55	1.29	0.051
		8/12/96	No	1700	7.78	0.083	15.4	1.53	1.37	0.053
	GM			978.02	7.74	0.07	14.20	1.52	1.32	0.04
	2006	5/8/06	No	150	7.7	0.0787	10.3	1.46	1.23	0.0286
		6/12/06	No	1600	7.6	0.1256	14	1.61	1.17	0.0464
		7/10/06	No	330	7.6	0.1238	15.6	1.52	1.24	0.0548
		8/14/06	No		7.8	0.1338	14.8	1.41	1.21	0.0659
	GM			429.45	7.67	0.11	13.51	1.50	1.21	0.05
	2016	5/11/16	No	91	7.79	0.0897	14.8	1.3	1.07	0.0472
		6/15/16	No	760	7.8	0.1069	14.5	1.26	0.921	0.0466
		7/13/16	No	280	7.96	0.0933	16.7	1.02	0.863	0.0492
		8/10/16	No	1000	7.92	0.0896	16.8	1.02	0.851	0.0501
	GM			373.04	7.87	0.09	15.66	1.14	0.92	0.05

Appendix Table A. 11 Aggregate Table

Station_name	Year	Fecal Coliform (CFU/100ml)	pH	Total Phosphorus (mg/L)	Temperature (°C)	Total Nitrogen (mg/L)	Nitrate-Nitrite (mg/L)	Ortho Phosphate (mg/L)
CedarRiver A438	1996	24.53	7.53	0.01	14.01	0.28	0.21	0.01
	2006	18.40	7.40	0.02	12.32	0.22	0.20	0.00
	2016	5.76	7.64	0.01	14.79	0.21	0.15	0.00
May Creek 0440	1996	137.56	7.58	0.06	13.69	1.51	1.34	0.03
	2006	135.30	7.90	0.07	13.38	1.45	1.25	0.03
	2016	57.37	7.93	0.06	14.79	1.44	1.25	0.03
Coal Creek 0442	1996	134.00	8.00	0.03	12.77	0.55	0.44	0.02
	2006	129.58	8.20	0.04	13.11	0.48	0.41	0.01
	2016	51.75	8.30	0.03	13.07	0.38	0.25	0.01
Kelsey Creek 0444	1996	308.98	7.09	0.10	14.51	0.77	0.54	0.06
	2006	126.17	7.64	0.12	14.63	0.68	0.44	0.06
	2016	32.75	7.35	0.14	15.19	0.39	0.10	0.06
Yarrow Creek A499	1996	84.73	7.95	0.07	12.58	2.30	2.65	0.05
	2006	78.57	7.92	0.09	12.13	2.56	2.48	0.05
	2016	38.92	8.01	0.08	11.94	2.57	2.31	0.05
Forbes Creek 0456	1996	854.55	7.56	0.09	14.21	0.85	0.59	0.06
	2006	129.06	7.20	0.14	14.30	0.78	0.39	0.06
	2016	42.12	7.02	0.30	13.84	1.04	0.14	0.08
Junaita Creek 0446	1996	252.69	7.56	0.05	15.31	1.82	1.64	0.03
	2006	327.70	7.62	0.13	13.61	1.50	1.21	0.08
	2016	139.10	7.48	0.07	14.39	1.34	1.17	0.04
Lyon Creek 0430	1996	316.60	7.71	0.05	13.99	1.33	1.21	0.03
	2006	416.84	7.58	0.07	12.37	1.36	1.11	0.03
	2016	96.62	7.80	0.06	15.36	1.10	0.92	0.03
McAleer Creek A432	1996	291.30	7.79	0.07	13.57	1.73	1.56	0.04
	2006	317.75	7.76	0.09	13.01	1.77	1.52	0.04
	2016	154.15	7.84	0.08	14.29	1.68	1.46	0.04
Thornton Creek 0434	1996	978.02	7.74	0.07	14.20	1.52	1.32	0.04
	2006	429.45	7.67	0.11	13.51	1.50	1.21	0.05
	2016	373.04	7.87	0.09	15.66	1.14	0.92	0.05

## APPENDIX B

Each of the two tables below represents the area (in acres) and percentage area of each reclassified land cover class along with their Aggregation Index (AI) for 1996, 2006, and 2016 for 10 different stations for two variable buffer widths:

Appendix Table B. 1 100m Riparian Buffer

100m								
Station_name	Year	Area_Urban (in acres)	Area_Natural (in acres)	Total_area (in acres)	% Area_Urban	% Area_Natural	AI_Urban	AI_Natural
CedarRiver A438	1996	18.46	20.01	52.92	34.87	37.82	70.07	65.84
	2006	17.79	18.46	50.26	35.40	36.73	70.42	65.99
	2016	17.34	22.46	52.48	33.05	42.80	71.74	70.72
May Creek 0440	1996	41.14	6.00	47.14	87.26	12.74	90.06	41.86
	2006	42.03	6.67	48.70	86.30	13.70	89.14	44.90
	2016	42.03	5.56	47.59	88.32	11.68	88.29	37.50
Coal Creek 0442	1996	43.36	2.89	46.92	92.42	6.16	85.91	22.22
	2006	43.14	3.34	46.48	92.82	7.18	86.11	31.82
	2016	46.48	1.33	47.81	97.21	2.79	88.69	14.29
Kelsey Creek 0444	1996	17.57	34.69	52.26	33.62	66.38	57.14	69.34
	2006	16.90	34.02	50.92	33.19	66.81	52.99	73.31
	2016	18.01	34.47	52.48	34.32	65.68	59.72	69.82
Yarrow Creek A499	1996	17.34	31.35	48.70	35.62	64.38	91.30	94.57
	2006	17.34	31.35	48.70	35.62	64.38	91.30	93.41
	2016	16.90	31.35	48.25	35.02	64.98	88.81	94.96
Forbes Creek 0456	1996	9.78	31.80	41.58	23.53	76.47	62.16	79.01
	2006	10.23	30.02	40.25	25.41	74.59	58.97	77.64
	2016	10.23	30.24	40.47	25.27	74.73	55.13	80.65
Junaita Creek 0446	1996	42.70	3.56	46.25	92.31	7.69	89.61	50.00
	2006	45.36	3.78	49.14	92.31	7.69	88.45	40.00
	2016	42.70	2.89	45.59	93.66	6.34	89.61	38.89
Lyon Creek 0430	1996	32.02	18.90	50.92	62.88	37.12	77.65	71.52
	2006	31.13	19.12	50.26	61.95	38.05	75.39	68.63
	2016	30.69	19.79	50.48	60.79	39.21	73.81	71.07
McAleer Creek A432	1996	29.13	21.79	50.92	57.21	42.79	64.44	53.41
	2006	29.80	21.35	51.15	58.26	41.74	65.98	51.74
	2016	30.02	21.57	51.59	58.19	41.81	64.63	54.60
Thornton Creek 0434	1996	41.14	5.34	46.48	88.52	11.48	87.43	36.84
	2006	40.92	5.34	46.25	88.46	11.54	87.35	39.47
	2016	42.25	5.11	47.37	89.20	10.80	88.35	38.89

Appendix Table B. 2 300m Riparian Buffer

300m								
Station_name	Year	Area_Urban (in acres)	Area_Natural (in acres)	Total_area (in acres)	% Area_Urban	% Area_Natural	AI_Urban	AI_Natural
CedarRiver A438	1996	45.59	71.83	150.32	30.33	47.78	71.13	82.62
	2006	44.92	71.60	150.55	29.84	47.56	70.40	83.06
	2016	46.03	74.27	152.32	30.22	48.76	70.39	83.04
May Creek 0440	1996	106.96	26.68	133.65	80.03	19.97	93.03	71.10
	2006	107.63	27.57	135.20	79.61	20.39	92.10	69.78
	2016	107.18	25.80	132.98	80.60	19.40	91.96	67.62
Coal Creek 0442	1996	130.53	8.23	140.09	93.17	5.87	91.38	34.43
	2006	132.98	8.23	141.21	94.17	5.83	91.63	36.07
	2016	134.09	7.12	141.21	94.96	5.04	92.73	42.31
Kelsey Creek 0444	1996	46.03	111.85	157.88	29.15	70.85	66.23	87.93
	2006	46.25	112.74	159.00	29.09	70.91	66.15	88.53
	2016	56.26	101.62	157.88	35.63	64.37	71.52	86.45
Yarrow Creek A499	1996	63.82	81.61	145.43	43.88	56.12	86.11	92.37
	2006	62.93	81.83	144.76	43.47	56.53	85.15	91.68
	2016	64.49	80.28	144.76	44.55	55.45	86.06	91.37
Forbes Creek 0456	1996	50.92	79.61	130.53	39.01	60.99	76.58	80.83
	2006	56.48	74.05	130.53	43.27	56.73	78.36	80.92
	2016	56.93	70.05	126.97	44.83	55.17	76.67	80.47
Junaita Creek 0446	1996	115.63	10.01	125.64	92.04	7.96	92.76	40.79
	2006	116.75	8.01	124.75	93.58	6.42	93.33	30.00
	2016	118.30	6.89	125.20	94.49	5.51	94.00	26.00
Lyon Creek 0430	1996	104.51	42.47	146.99	71.10	28.90	83.82	62.99
	2006	102.96	43.58	146.54	70.26	29.74	82.20	59.34
	2016	104.07	42.70	146.77	70.91	29.09	82.96	62.64
McAlear Creek A432	1996	94.95	58.26	153.21	61.97	38.03	76.85	61.30
	2006	93.84	58.71	152.55	61.52	38.48	75.44	61.01
	2016	94.29	59.37	153.66	61.36	38.64	76.18	62.08
Thornton Creek 0434	1996	130.31	16.46	146.77	88.79	11.21	92.07	43.85
	2006	133.42	14.90	148.32	89.96	10.04	93.57	44.44
	2016	133.42	14.90	148.32	89.96	10.04	93.57	44.44

## APPENDIX C

The table below show the detailed results of the trend analysis for 7 water quality parameters:

Water quality parameters	% Change in Water Quality Parameters														
	Cedar River A438			May Creek 0440			Coal Creek 0442			Kelsey Creek 0444			Yarrow Creek A499		
	1996-2006	2006-2016	1996-2016	1996-2006	2006-2016	1996-2016	1996-2006	2006-2016	1996-2016	1996-2006	2006-2016	1996-2016	1996-2006	2006-2016	1996-2016
Fecal Coliform (CFU/100ml)	24.99	68.70	76.52	1.64	57.60	58.30	3.30	60.06	61.38	59.16	74.05	89.40	7.27	50.46	54.06
pH	1.80	3.23	1.37	4.11	0.46	4.59	2.43	1.29	3.75	7.76	3.80	3.66	0.36	1.11	0.75
Total Phosphorus (mg/L)	31.61	27.74	4.89	14.74	0.92	13.69	8.01	17.56	10.96	16.11	16.91	35.75	28.68	16.13	7.92
Temperature (°C)	12.09	20.05	5.53	2.26	10.59	8.09	2.66	0.28	2.37	0.81	3.84	4.67	3.58	1.53	5.06
Total Nitrogen (mg/L)	19.63	4.85	23.53	3.98	0.51	4.46	12.83	20.50	30.70	10.59	43.49	49.48	11.23	0.52	11.81
Nitrate-Nitrite (mg/L)	2.47	25.19	27.03	6.95	0.34	7.27	7.57	38.36	43.02	17.97	76.44	80.68	6.38	6.96	12.90
Ortho Phosphate (mg/L)	53.63	11.28	58.86	6.33	14.48	7.23	24.27	3.54	26.95	5.44	4.29	0.92	10.29	0.48	10.73

Water quality parameters	% Change in Water Quality Parameters														
	Forbes Creek 0456			Junaita Creek 0446			Lyon Creek 0430			McAleer Creek A432			Thornton Creek 0434		
	1996-2006	2006-2016	1996-2016	1996-2006	2006-2016	1996-2016	1996-2006	2006-2016	1996-2016	1996-2006	2006-2016	1996-2016	1996-2006	2006-2016	1996-2016
Fecal Coliform (CFU/100ml)	84.90	67.36	95.07	29.69	57.55	44.95	31.66	76.82	69.48	9.08	51.49	47.08	56.09	13.13	61.86
pH	4.75	2.48	7.12	0.89	1.84	0.97	1.63	2.92	1.25	0.34	1.07	0.72	0.81	2.51	1.68
Total Phosphorus (mg/L)	55.24	119.31	240.47	148.38	43.10	41.32	39.69	14.54	19.39	23.65	14.74	5.43	58.66	16.36	32.71
Temperature (°C)	0.60	3.22	2.64	11.12	5.74	6.02	11.59	24.13	9.75	4.14	9.84	5.29	4.85	15.96	10.34
Total Nitrogen (mg/L)	7.90	33.34	22.80	17.87	10.22	26.26	2.68	18.81	16.63	2.16	4.94	2.88	1.24	23.74	24.68
Nitrate-Nitrite (mg/L)	33.06	64.35	76.14	25.87	4.05	28.88	7.87	17.10	23.62	2.55	3.56	6.01	8.44	23.91	30.34
Ortho Phosphate (mg/L)	6.71	33.40	42.35	160.26	54.32	18.88	11.72	7.62	4.99	4.85	2.85	2.14	8.91	3.13	12.33

## APPENDIX D

The tables below show the detailed regression outputs for pH and TP in the 100m riparian buffer model:

Appendix Table D 1 Summary output for pH

<b>Model Summary</b>					
Multiple R	0.6290				
R Square	0.3957				
Adjusted R Square	0.3509				
Standard Error	0.2380				
Observations	30				
<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	1.0017	0.5009	8.8400	0.001114
Residual	27	1.5298	0.0567		
Total	29	2.5315			
<b>Coefficients</b>					
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>	
Intercept	6.67241	0.43372	15.38404	0.000000	
% Natural	-0.00055	0.00243	-0.22720	0.821976	
AI Urban	0.01346	0.00474	2.83820	0.008509	

Appendix Table D 2 Summary output for TP

<b>Model Summary</b>					
Multiple R	0.4730				
R Square	0.2237				
Adjusted R Square	0.1662				
Standard Error	0.0495				
Observations	30				
<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	0.0191	0.0095	3.8908	0.032750
Residual	27	0.0662	0.0025		
Total	29	0.0853			
<b>Coefficients</b>					
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>	
Intercept	0.11035	0.09025	1.22265	0.232026	
% Natural	0.00071	0.00051	1.40943	0.170122	
AI Urban	-0.00072	0.00099	-0.73153	0.470756	

## APPENDIX E

The tables below show the detailed regression outputs for pH, TP and Ortho-phosphate in the 300m riparian buffer model:

Appendix Table E 1 Summary output for pH

<b>Model Summary</b>					
Multiple R	0.5291				
R Square	0.2799				
Adjusted R Square	0.2266				
Standard Error	0.2598				
Observations	30				
<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	0.7087	0.3543	5.2486	0.011870
Residual	27	1.8229	0.0675		
Total	29	2.5315			
<b>Coefficients</b>					
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>	
Intercept	6.54876	0.92758	7.06005	0.000000	
% Natural	-0.00118	0.00408	-0.29035	0.773770	
AI Urban	0.01420	0.00969	1.46520	0.154415	

Appendix Table E 2 Summary output for TP

<b>Model Summary</b>					
Multiple R	0.5889				
R Square	0.3468				
Adjusted R Square	0.2984				
Standard Error	0.0454				
Observations	30				
<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	0.0296	0.0148	7.1678	0.003185
Residual	27	0.0557	0.0021		
Total	29	0.0853			
<b>Coefficients</b>					
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>	
Intercept	-0.36041	0.13024	-2.76721	0.010083	
% Urban	0.00416	0.00129	3.20972	0.003415	
% Natural	0.00517	0.00143	3.62736	0.001176	

Appendix Table E 3 Summary output for Ortho-phosphate

<b>Model Summary</b>					
Multiple R	0.55901417				
R Square	0.31249685				
Adjusted R Square	0.26157069				
Standard Error	0.01701963				
Observations	30				
<b>ANOVA</b>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	0.00355496	0.00177748	6.13627355	0.006356358
Residual	27	0.00782103	0.00028967		
Total	29	0.011376			
<b>Coefficients</b>					
	<i>Coefficients</i>	<i>Std. Error</i>	<i>t Stat</i>	<i>P-value</i>	
Intercept	-0.1384244	0.06075852	-2.2782712	0.03084181	
% Natural	0.0009305	0.00026701	3.48493479	0.00169797	
AI Urban	0.00175507	0.00063477	2.76490071	0.01013848	