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Effects of Land Cover Change on Water Quality in Urban Streams at Two Spatial Scales

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Abstract
This study examines the relationships between land cover change and water quality change in three urbanizing watersheds in the Pacific Northwest region of the United States: Burnt Bridge Creek, Salmon Creek, and the Tualatin River. All three watersheds have had many of their water quality parameters exceeding Total Maximum Daily Loads as required by their state's environmental agencies in the past decades. By using the National Land Cover Datasets classified by the United States Geological Survey (USGS) for 1992, 2001 and 2006 and water quality data for a period between 1991 and 2010, this paper aims to examine whether changes in land cover are causing changes in water quality at two different spatial scales - at the sub-watershed scale and at a 100 meter riparian buffer scale. We used spatial regression models to identity the major determinants of changes in water temperature (WT), total suspended solids (TSS), dissolved oxygen (DO), and total phosphorus (TP) over time at different scales. The results show that each parameter reacts differently to land cover change depending on the scale of analysis. Both DO and WT showed significant relationships with land cover parameters on the watershed scale but not as much on the riparian buffer scale. TP shows significant relationships at the watershed scale, but TSS shows no significant relationships at the watershed scale. WT shows the only significant change in water quality over the past twenty years and is positively related to change in urban land cover. Topographic variables become significant in explaining the variations in WT and TP at the riparian scale. DO is mostly explained by mean slope for both 1992 and 2001 at both scales, but urban land cover became an important predictor in 2006 at both scales. Our analysis also suggested that there may be a potential lag between changes in land management and changes in water quality across different scales.

Keywords
Water quality, urbanization, spatial analysis, scale, Pacific Northwest

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1. INTRODUCTION

The study of the relationship between land cover and water quality has been an important topic in geographical and environmental research for many years. As humans have constantly modified the land cover of Earth (Turner et al. 2007), and as urban population is projected to increase in coming decades with more than 60% of global population projected to live in urban areas by 2030 (UN 2013), it is important to understand how changes in land cover have many measurable impacts on water quality in urbanizing watersheds (Duh et al. 2008). Previous studies on this topic find that, both urban and agricultural lands, typically associated with domestic and industrial wastewater discharges, are indicators of poor water quality (Alberti et al. 2007; Boeder and Chang 2008; Cunningham et al. 2010; Liu et al. 2012; Praskievicz and Chang 2011).

The absolute amount of land cover types and different spatial patterns of land covers have shown to have different effects on water quality (Alberti et al. 2007). In an urbanizing Oregon watershed, Boeder and Chang (2008) found that agricultural land is more positively correlated with non-point source pollutants in streams than residential land. Yet, Lee et al. (2009) found one such pollutant, total phosphorus, to be positively correlated with percent urban area and negatively correlated with percent forested area, but had no significant correlation with percent agricultural area in South Korea. Figueirdo et al. (2010) found that other chemical pollutants such as sodium and chloride increase with an increase in crop-land cover in the Amazon. On the other hand, they found that other water quality parameters, such as temperature and dissolved oxygen, are more significantly correlated with percent land cover (Figueirdo et al. 2010). The differences in results of all these studies indicate that many other characteristics of a river basin need to be considered when studying land cover impacts on water quality.

For one thing, the physical characteristics of stream drainage also influence water quality. It is believed that drainage density will affect the runoff in an area and therefore affect the nutrient loading in a stream (Rao 2009). Morgan and Kline (2011) found a wide range of nutrient concentrations in a stream for different Strahler stream orders, with total phosphorus being significantly lower in third-order streams than in first and second order streams. In a study of agricultural watersheds in New Zealand, Buck et al. (2004) identified that upstream land use was more influential to water quality in larger streams, while local land use and other factors may be more important in smaller streams. Since the results of statistical analysis might be an artifact of the chosen scale, Gove et al. (2001) suggested that researchers should investigate the relationship between land cover and water quality at multiple scales.

The effects of both spatial and temporal scale could also cause disparities in the relationship between land cover and water quality (Allan, Erickson, and Fay 1997; Townsend et al. 2003). In terms of spatial scale, the sub-basin scale seems to show more of a correlation between land cover and water quality than the riparian buffer scale does (Alberti et al. 2007; Pratt and Chang 2012; Tong and Chen 2001). Contrary to this, Cunningham et al. (2010) found that urbanization had more of an effect on water quality at the riparian buffer scale. Similarly, Amiri and Nakane (2009) identified that focusing on riparian buffer scale could result in more robust regression models representing the relationship between land use change and in-stream water quality.

In terms of temporal scale, in humid temperate climates where there is uneven distribution of seasonal precipitation amount, distinct seasonal variations in water quality and different determinants of water quality were noted (Pratt and Chang 2012). Figueirdo et al. (2010) showed differences between spring and fall seasons on the contribution of land cover types to chemical water pollutants. Miller et al. (2011) demonstrated that flow, agriculture and urban land are predictors of a significant difference in total suspended solids between periods of base flow and storm flow in a stream in the Lower Kaskaskia River in Southern Illinois. Therefore, when flows differ by season this can lead to significant seasonal differences in certain water quality parameters. Aggregating seasonal data could mask changes in water quality. Most studies considered season when investigating the temporal difference of water quality; however, few have examined the long-term (over ten years) effects of land cover change on water quality.

When studying possible long-term temporal effects, the majority of studies use space as a proxy for time (Carter et al. 2009; Wagener et al. 2010). Carter et al. (2009) explain that one limitation of using the space-for-time approach is that most of these studies are done over a short time period. However, the hydrologic system and processes are not the same now as they were in the past, because human influences have modified the hydrologic responses (Wagner et al. 2010). When a short term period was used for identifying the relationship between land cover and water quality, even if seasonal fluctuations are considered, one cannot account for longer term fluctuations of climate or the processes that led to urbanization and new hydrologic systems (Carter et al. 2009).

There have been studies to quantify the effects of land cover on water quality, but such previous studies used a relatively short period of data (Carter et al. 2009). In the Portland, Oregon area an attempt was made at a four year study of watershed-scale effects of stormwater best management practices (BMPs) in the Tualatin River Basin. Unfortunately, four years proved to be an insufficient amount of time to detect changes (Carter et al. 2009). Even attempts at monitoring stormwater BMPs over as long as a ten-year time period have not been able to show significant results (Carter et al. 2009). Similarly, Langland et al. (2006) suggested a time lag in obtaining results when looking at the effects of riparian restoration on stream health. The possibility of a time lag highlights the importance of conducting studies over a longer period of time. The publically available United States Geological Survey (USGS) land cover data has allowed researchers to look at how the change in land cover over time will affect water quality today. Scott et al. (2002) found that change in forested area over a twenty year period showed a significant negative correlation with both nitrogen loads and stream water temperature at the time of sampling. The goal of this study is to be able to quantify how the processes of changing land cover over a long period of time have contributed to a change in stream health by way of water quality.

The ability to collect data over long time spans can lead to innovative developments in improving water quality and stream health. This study uses data from water quality monitoring stations over a twenty year period for three watersheds in the Pacific Northwest: Burnt Bridge Creek and Salmon Creek in Washington; and the Tualatin River in Oregon. Using the water quality data along with the USGS National Land Cover Datasets (NLCDs), this paper aims to answer the following three questions:

1. Has there been a significant change in water quality over the past twenty years? Do these trends vary by water quality parameter? What watershed characteristics explain such trends?
2. Has the effect of land cover and other watershed characteristics on water quality changed over time?
3. How does scale (sub-watershed vs. riparian buffer scale) influence the relationship between land cover and water quality?

There are three major parts in this paper corresponding to the three aforementioned research questions:

Part one: The first part involves examination of how water quality parameters have changed between 1991 and 2010. With increase in urbanization it is hypothesized that pollutants and temperature will increase whereas dissolved oxygen in the water will decrease.

Part two: Regression models were constructed for the three year time period surrounding each NLCD 1992, 2001 and 2006. The goal is to investigate if independent variables remain the same for predicting the same water quality parameters in each of these time periods. With increasing urbanization, it is suspected that percent urban land cover will become a more important predictor of water quality in later years than in 1992. We also investigate whether change in forested area and change in urban area from 1992 to 2006 at both the sub-watershed and riparian buffer scales are good predictors of water quality in 2006.

Part three: We examined which scale (sub-watershed versus riparian-buffer) is more appropriate when analyzing the effects of land cover and topography on water quality. The study proposes that the sub-watershed scale will show more of the cumulative effects of urban and agricultural land cover on water quality, whereas the buffer scale will show the immediate effects of topographic factors such as slope. It is hypothesized that the sub-watershed scale analysis explains more of the variations in non-point source pollution water quality parameters than does the buffer scale.

2. DATA AND METHODS

2.1 STUDY AREA

The watersheds in the study area are located in the Pacific Northwest states of Oregon and Washington. The watersheds are situated around the confluence of the Columbia and Willamette rivers (Figure 1), Salmon Creek and Burnt Bridge Creek on the northeast in Clark County, Washington and the Tualatin River to the southwest mainly in Washington County, Oregon. Located in a marine west coast environment, the area is marked with

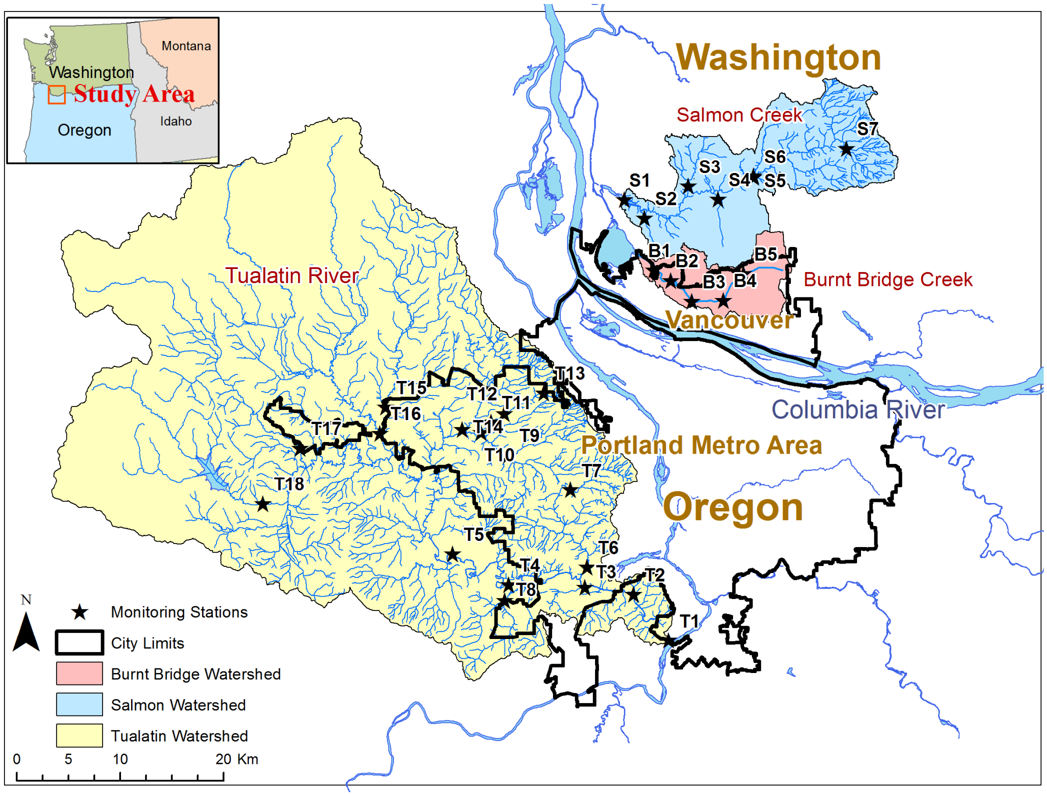

Figure 1. Study area

warm dry summer temperatures and a long winter season with constant precipitation (Praskievicz and Chang 2009). Due to marked differences in runoff between the two seasons this study will only focus on the dry season. Additionally, monitoring was far more frequent in the dry season than in the wet season. The watersheds were chosen for three reasons: significant changes in the land cover spanning the watersheds in the past twenty years, problems with maintaining water quality in each watershed, and data availability.

Figure 2 shows land cover for the year 1992 (A), 2001 (B) and 2006 (C), respectively. Between 1992 and 2001 the encroachment of urban development is visible, and between 2001 and 2006 one can see the replacement of forested area with agricultural area, specifically in the Tualatin River Basin. Located within the urban growth boundary, the eastern region of the Tualatin River Basin has experienced significant urban development in the past twenty years, and more development is projected near the urban fringe in coming decades (Hoyer and Chang 2014). Similarly, the Salmon Creek and Burnt Bridge Creek Basins are located at the outskirts of Vancouver, Washington, and have also seen significant growth and development within the twenty-year period (Chang et al. 2014).

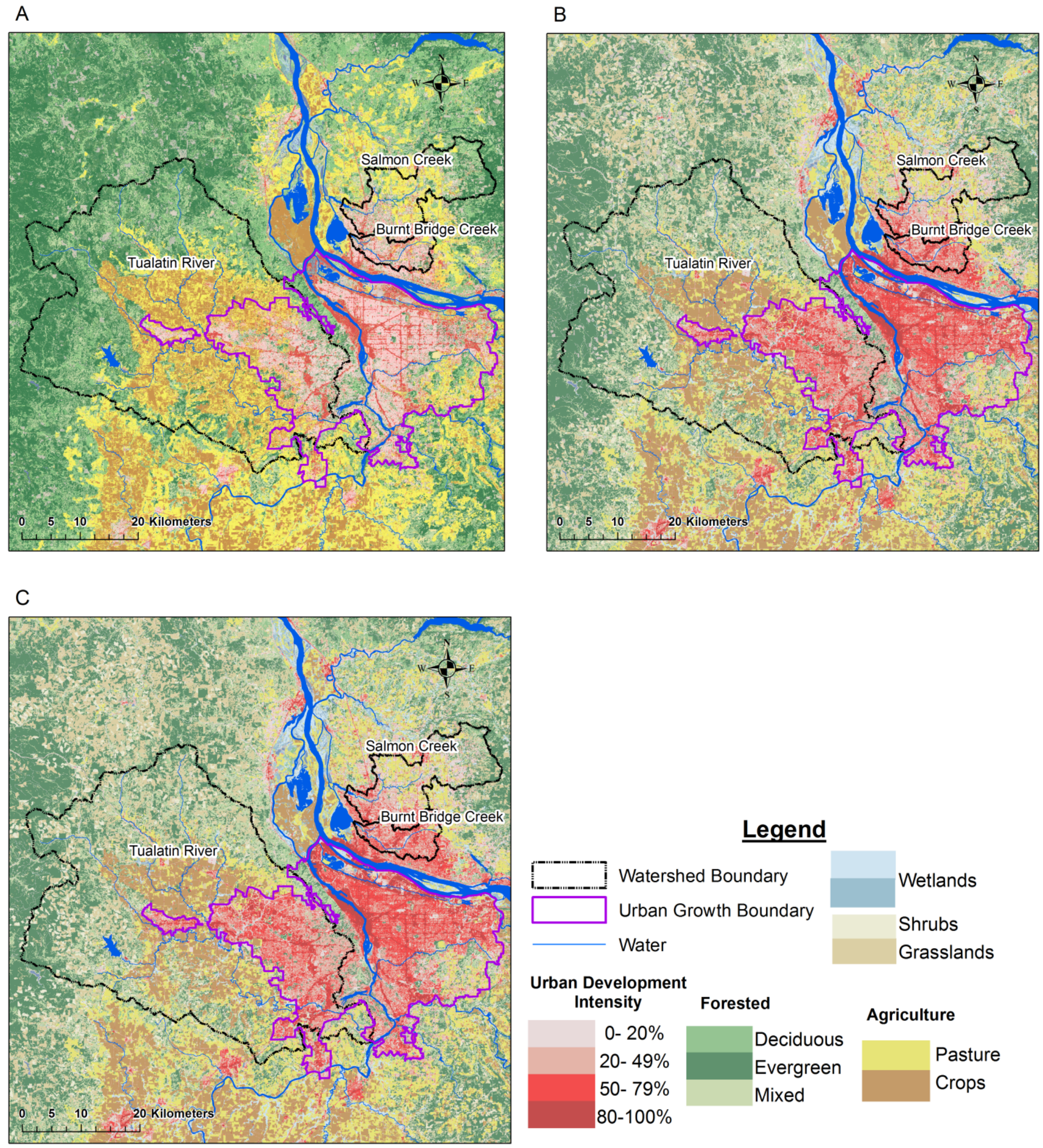

Figure 2. Land cover in 1992 (A), 2001 (B) and 2006 (C) (Source: USGS)

With their proximity to significant land developments associated with population growth, these watersheds have struggled to maintain good water quality standards. The Clean Water Act 1972 (CWA) requires that each state develop specific water quality standards in order to maintain the health of their streams. Every two years each state is to identify which of their waters do not meet the minimum standards set by CWA as per Section 303(d) (ODEQ 2012), referred to as '303 (d) lists'. The latest released 303 (d) lists have all three watersheds listed for a number of parameters (ODEQ 2012, WADE

2009). As such, all three watersheds are frequently monitored for water quality by governmental agencies as shown in Table 1.

These monitoring efforts allowed us to use twenty years of data for our analysis. With the available data, 29 monitoring stations in the three watersheds were identified for the study, eighteen in the Tualatin River watershed, six in the Salmon Creek watershed, and five in the Burnt Bridge watershed (Figure 1). The sub-watersheds represent a range of development, from highly developed watersheds within the Portland and Vancouver city limits to rural and forested watersheds further out.

2.2 DATA

Table 1. Summary of data sources

Data	Time frame	Frequency	Source
Water Quality (Burnt Bridge Creek)	1990 to 1999; 2003 - 2010	Bi-weekly grab samples (only May thru October in years 1990-1999)	City of Vancouver (2012)
Water Quality (Salmon Creek)	1990 to 2010	Bi-weekly grab samples	Clark County Department of Environmental Services (2012)
Water Quality (Tualatin River)	1990 to 2010	Weekly grab sample (May thru September) Bi-weekly grab samples (October thru April)	Clean Water Services (2012)
Stream Order		One	USGS National Hydrography Dataset (2013)
Land Cover	1992, 2001, and 2006	Three total	USGS National Land Cover Dataset (2012)
Digital Elevation Model	2010	One	USGS Digital Elevation Model 10m resolution (2012)

USGS= United States Geological Survey

Table 1 summarizes the sources of the data used for analysis. The four water quality parameters examined in this study are water temperature (WT in °C), total suspended solids (TSS in mg/L), dissolved oxygen (DO in mg/L), and total phosphorus (TP in mg/L). WT and DO were measured in situ using a portable YSI meter. TSS was calculated using a weighed filter based on the EPA 160.2 method. TP was measured using persulfate digestion and automated ascorbic acid based on the EPA 365.1 method

(Rice et al. 2012). These agencies also collect continuous data for WT and other water quality parameters in more recent years, as well as less frequent wet season data, however, this data was not consistent over the twenty years period and could not be used. Also to note, is that the years of 2000 to 2002 are missing data for Burnt Bridge Creek, in this case we used simple linear interpolation between 1999 and 2003 for these three missing years.

The physical characteristics, DO and WT, need to be maintained for stream habitat and aquatic life. Low concentrations of DO can cause stress on aquatic animals (Davie 2002). WT is also important for species survival. Both Burnt Bridge Creek and the Tualatin River are considered salmon and trout rearing streams, whereas Salmon Creek is considered a core summer habitat stream, and as such the state standard was set at 18 °C for a seven-day average for all three (ODEQ 2012, WADE 2011) during the study period. TP was chosen as an indicator of anthropogenic influence as its supply in the stream tends to be a result of human, animal, and industrial waste (Davie 2002). Finally, although TSS is not listed a parameter to be measured as required by the CWA, it was selected as a proxy for turbidity. TSS is a measure of all the organic and mineral particles in a stream and is considered an indication of land and stream bed erosion (Davie 2002). Clark County, the City of Vancouver, and Clean Water Services provided shape files with monitoring stations and stream networks for their respective watersheds.

The land cover and topographic characteristics represent the independent variables. Raster files for the NLCDs were obtained online from the Multi-Resolution Land Cover Consortium (USGS 2012). Using the classifications established by the USGS, each land cover value was considered to be one of the following land types: urban, forested, agricultural, wetlands and other. Percent land cover for each land type was then calculated. The stream network file was taken from USGS National Hydrography Dataset (NHD), which also contained the Strahler stream order number (USGS 2013). The NHD stream network was also used to calculate drainage density. The topographic characteristics considered were area, slope, and elevation. Both the mean and standard deviation of slope and elevation were calculated at two different spatial scales - the individual sectioned-watershed scale and the buffered scale - to reflect the spatial variability of these topographic variables.

2.3 Spatial Analysis

Once data was collected the areas of watershed were established. Based on previous studies, a sectioned-watershed (hereafter we referred to sub-watershed) and a riparian buffer scale were determined appropriate units (Cunningham et al. 2010, Figueiredo et al. 2010, Miller et al. 2011, Pratt and Chang 2012). Using ArcMap 10.1, the 29 monitoring stations were selected and mapped. We refer to the points of these stations as 'sites'. The USGS 10 meter resolution digital elevation model (DEM) was used to delineate the watershed boundary from each monitoring point. We also derive various watershed morphometric, topographic and land cover variables at both sub-watershed and buffer scales that are needed as the explanatory variables in our regression models (see the statistical analysis section below). Drainage density was then calculated for each site by dividing the total stream network length upstream of the site with the watershed area upstream of the site. In order to create the sub-watershed portions each watershed was clipped from the watersheds upstream, so that in the end there were 29 separate non-overlapping watersheds. ArcMap 10.1 was again used to create a 100-meter buffer on both sides of streams. These newly buffered streams were then clipped to the watersheds that contained them to ensure that each site was covered by a separate and unique buffered area. Figure 3 illustrates the clipped sub-watersheds and buffered area of the Tualatin basin. ArcMap 10.1 was also used to calculate the land cover and topographic characteristics. In order to calculate the number of raster cells of each land cover classification, the Tabulate Area tool was used, and the output table was used to calculate the percentages of each land cover type. This was done for all three NLCDs 1992, 2001 and 2006. To obtain the topographic characteristics, the Zonal Statistics tool was used for each sub-watershed and buffered area. The output of this tool contained the mean and standard deviation for both the elevation and the slope of every site at both scales.

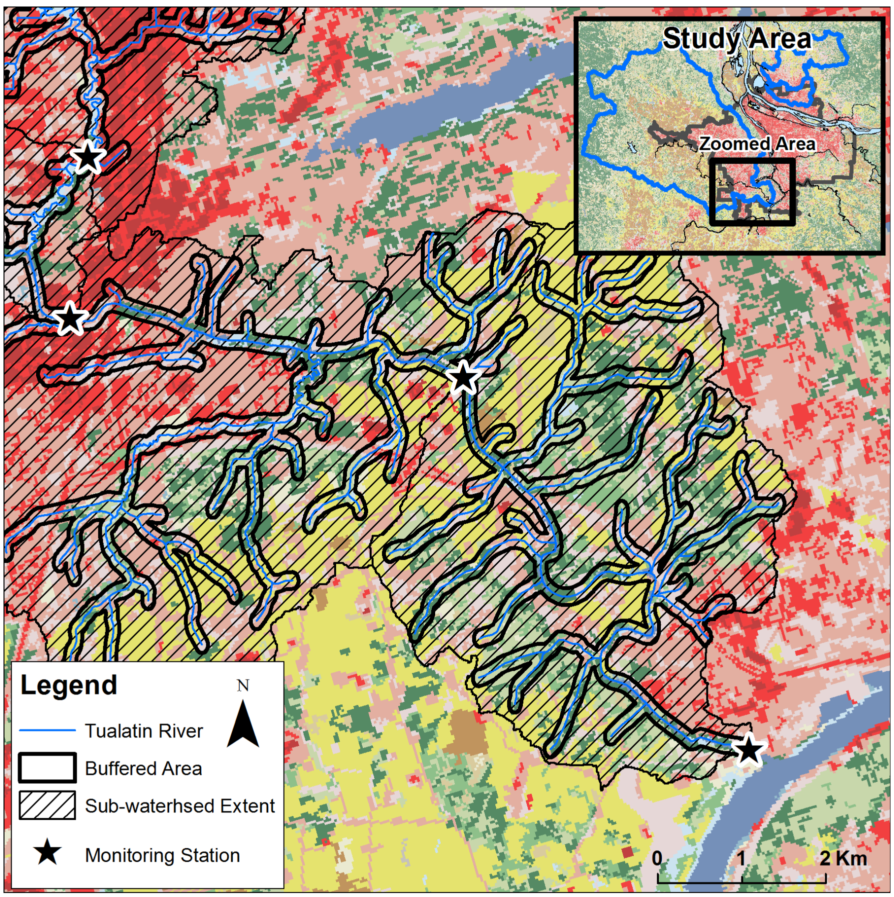

Figure 3. Scales of analysis (Data source: Clark County Department of Environmental Services, Clean Water Services, and USGS)

2.4 STATISTICAL ANALYSIS

Due to data availability and significant differences in water quality between the wet and dry seasons, we only examined water quality during the dry season in the region, which are the months of May through October (Boeder and Chang 2008; Chang 2007). First, monthly mean values of each parameter were calculated for each site from 1991 to 2010 and normal distribution was tested using the Kolmogorov–Smirnov (K-S) test in IBM SPSS 20. In some cases, the water quality data were log-transformed to correct for abnormal distribution. Second, the monthly average data were used to detect trends in water quality (to answer research question 1) using a non-parametric Mann-Kendall's test that has been widely used in the literature (Chang 2008; McLeod et al. 1990). Third, monthly mean data for each parameter was also used to calculate the slope of the regression line as a representation of change in water quality. Fourth, the three-year geometric means of each water quality parameter representing the early 1990s (1991-1993), the early 2000s (2000-2002), and the mid-2000s (2005-2007) were also calculated. These years are centered around 1992, 2001, and 2006, respectively and were chosen to match the available years of land cover data. As noted in Pratt and Chang (2012), a geometric mean is more appropriate than arithmetic mean when data are not normally distributed. The geometric mean is also a measure of the central tendency of the data, and is calculated using the following equation:

$$Geometric\ mean = ((X_1)(X_2)(X_3)........(X_n))^{1/n}. \tag{1}$$

Fifth, we developed two different types of regression models to explain spatial and temporal variations of water quality. One type of regression model is to use the slope of each water quality parameter as a dependent variable for examining the relationship between the change in land cover and change in water quality (to answer research question 1). Another type of model is the use of the three-year geometric means of each parameter as a dependent variable and other watershed characteristics, including land cover change, as explanatory variables to examine whether the determinants of water quality have changed over the three snapshot periods (the early 1990s, the early 2000s, the mid-2000s) at different spatial scales (to answer research questions 2 and 3).

Multiple ordinary least squared (OLS) stepwise regression analysis was conducted in SPSS to identify significant independent variables for each parameter at the two spatial scales for the three periods and the 20-year period. After the significant independent variables were identified in OLS regression analysis, the same variables were used for spatial regressions in GeoDa (Anselin et al. 2006). A spatial weight matrix was created for the sectioned-watersheds and applied for constructing regression models. Similar to the previous study (Chang 2008), we tested both spatial lag and spatial error models and chose a better model based on the Akaike information criterion (AIC) value. The model with the lower AIC value was then used for reporting the results. All the regression analysis was tested for significance at the two-tailed 0.05 value.

3. RESULTS AND DISCUSSION

3.1 CHANGES IN WATER QUALITY BETWEEN 1991 AND 2010

Table 2. Results of the Slope and Mann-Kendall's Tau Correlation Coefficient of July geometric means, 1991 - 2010 (Slope of the regression listed above and coefficient listed below)

Location	WT	TSS	DO	TP
B4 Mainstem			-0.134	
			-0.556*	
S2 Tributary	0.094			
	0.370*			
S4 Tributary	0.127			
	0.471*			
S5 Mainstem	0.220			
	0.524**			
S6 Tributary	0.216			
	0.467*			
T1 Mainstem	0.777			
	0.614**			
T2 Mainstem	0.701		-0.278	0.003
	0.626**		-0.474**	0.579**
T3 Mainstem	0.592			
	0.474**			
T4 Mainstem	0.370	-0.401		
	0.497**	-0.439**		
T5 Mainstem	0.259			
	0.464**			
T6 Tributary			-0.048	
			-0.392*	
T7 Tributary		-1.099	-0.101	
		-0.526**	-0.368*	
T8 Tributary		-0.145		
		-0.386*		
T9 Tributary			0.103	
			0.426*	
T13 Tributary		-0.510		-0.004
		-0.383*		-0.517**
T14 Tributary				0.002
				0.389*
T18 Tributary	-0.114		-0.230	-0.001
	-0.509**		-0.810*	-0.467**

Sample Size n=20 years

* Significant at the □= 0.05 level, ** Significant at the α =.01 level

Table 2 shows significant increase and decrease of the July monthly geomean of each parameter per site. The results of each parameter's trends per site are mapped out in Figure 4. Water temperature shows a significant increase in five sites in the middle Tualatin River (T1, T2, T3, T4, T5) and four sites in Salmon Creek (S2, S4, S5, S6) (Table 2 and Figure 4). Water temperature increases in areas that have undergone more urbanization between the years of 1991 and 2001. Urbanization typically results in a loss of canopy cover that will cause less shading of the stream, and thus raise water temperature (Chang and Psaris 2013). Water temperature responds to changes in land cover more readily than the other parameters. This supports the idea of different time lags by water quality parameters in response to change in land use and land cover (Langland et al. 2006). It is interesting to note that water temperature did not increase in many tributary stations in the Tualatin River regardless of ongoing urban development. It may be that some restoration efforts in these tributary stations are effective (Chang and Lawler 2011).

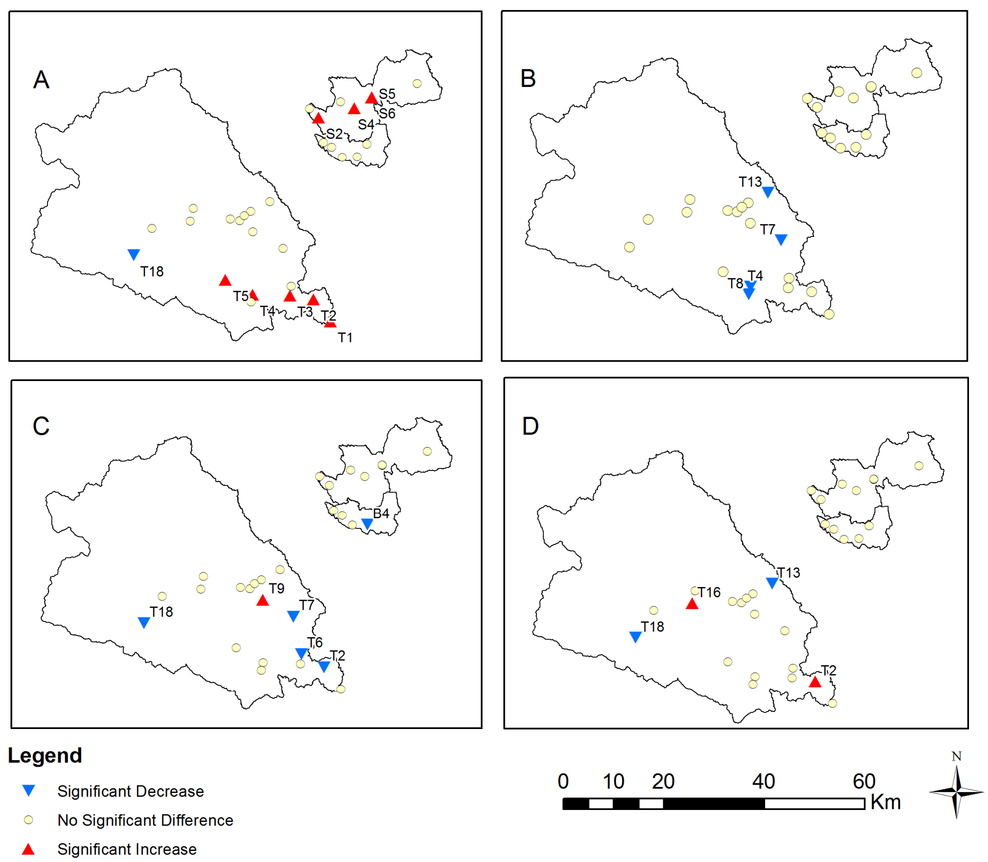

Figure 4. Changes of water quality between 1991 and 2010, decrease and increase are significant at the α= 0.05 value. Water Temperature (A); Total Suspended Solids (B); Dissolved Oxygen (C); Total Phosphorus (D)

TSS decreased significantly at four sites that are either within or close to the urban growth boundary in the Tualatin River (T4, T7, T8, T14). The change may be related to either the lack of sediment sources in existing developed areas or best land management practices that are effective in retaining more sediment on landscape.

Dissolved oxygen shows somewhat different trends than water temperature. One mainstream site (T2) and three tributary sites (T6, T7, T18) in the Tualatin show significant decreases in DO. Only one site in Burnt Bridge Creek (B4) shows a significant decrease in DO. One tributary site in the Tualatin (T9) shows a significant increase in DO.

TP increased in two sites (T2, T16) and decreased significantly in two stations (T13, T18), all located in the Tualatin River. Given that the soils in the Tualatin naturally have high phosphorus content (Boeder and Chang 2008), such increases or decreases are likely to be affected by other land management factors such as riparian management in new residential areas (T2, T16) and upland forested land enhancement (T13, T18). Further investigation is needed to verify the effects of different land management practices on TP.

Table 3. Results of spatial regression model for changes in water quality parameters over time

Parameter	Spatial regression models	R^2	Model
WT			
full	0.114•SO +.002•Slope(mean) + .344•ΔUrban + 0.127	0.6383	SE
buffer	0.729•ΔUrban + 0.771•ΔWetlands + 0.121	0.6528	SL
TSS			
full	0.031•Slope(sd) + 0.458	0.2013	SE
buffer	0.009•Slope_mean + 0.368	0.4524	SE
DO			
Full	.0002•Density + .16	0.163	SL
Buffer	no significant regressors		
TP			
Full	0.071•ΔForest - 0.244•ΔWetlands + 0.011	0.3439	SL
Buffer	-0.047•ΔUrban + 0.011	0.3293	SE

SE = Spatial error model; SL= Spatial lag model

* Significant at the p= 0.05 level

** Significant at thep =.01 level

full= sub-watershed scale; sd= standard deviation; Δ=change in percentage

When examining how water quality has changed over time in relationship to land cover, topographic, and stream network characteristics, each parameter showed different results. Table 3 shows the results of the spatial regression models. For change in WT, there is a positive association with change in urban area at both scales. Change in TSS is positively regressed with the standard deviation of the slope at the sub-watershed scale, and the arithmetic mean of the slope at the buffer scale. Drainage density is the only significant predictor of change in DO at both scales, with no discernable difference in predictability at both scales. Change in forest area is positively associated with TP, whereas change in wetlands is negatively regressed with TP at the sub-watershed scale. However, at the buffer scale, change in urban area is negatively related to change in TP. This is not expected, but it may indicate that the percent of urban area close to a stream cannot fully account for all changes in a stream.

3.2 Relationship between land cover and water quality in three different periods

When examining the individual three-year periods that are related to the three NLCDs years of 1992, 2001 and 2006, there are many more significant results than for the changes over time (Table 4). There are also differences among the three different points in time. In 2001 and 2006 all parameters show statistical significance with land cover and/or topographic features. However, in 1992 none of the topographic or dominant land cover variables are shown to be significant predictors of TP. Water temperature is negatively associated with forest land cover at the buffer scale in 2001 and 2006 but not in 1992. This may be related to various stream enhancement projects including riparian planting in some tributaries of the Tualatin River since the late 1990s. Even though urban areas increased at the sub-watershed scale, some areas have been reforested at the buffer scale as part of stream enhancement programs. However, because of the lag time for tree growth, there may not be sufficient canopy to provide shading in earlier years (Cochran and Logue 2011). Additionally, if storm water pipes divert water directly into streams rather than passing through riparian areas, riparian planting may not be effective in improving stream water quality.

Mean slope is consistently an important predictor of TSS throughout the three years, although the relationships are either positive (2001 and 2006) or negative (1992). TSS represents the particulate matter in the stream, and as such topographic features such as slope are better predictors of TSS as they relate directly to the runoff entering the stream (Chang 2008). Therefore, it makes sense to see that mean slope is the one constant predictors of TSS. On the other hand, the effect of different land covers on TSS differs by year. In 1992, the percent urban area was significant but in later years, either the percent forested area or percent agricultural area was significant in explaining the variations in TSS. In 1992 when the region had far more agricultural land, percent urban area had a positive relationship with TSS at both scales. However, in 2006, when the region was more developed, percent agricultural area had a positive relationship with TSS. The swapping of land cover types acting as predictors for TSS in different years could be related to new urban development in the study basins. As urbanization progresses, new construction sites might provide additional sources of sediment in earlier years, but as urbanization matures, sediment supply could be depleted.

Table 4. Results of spatial model regression results for three time periods

Parameter	Spatial regression models	R^2	Model
DO			
1992 full	0.087•Slope_mean +1.603•Elevation_sd(ln) + 915.164•Wetlands - 0.025•Elevation_mean - 28.35•OtherLC + 1.97	0.7216	SE
1992 buffer	0.074•Slope_mean + 2.136	0.6714	SE
2001 full	8.73•Agriculture + 5.646•Urban + 1.932	0.8589	SE
2001 buffer	3.651•Elevation_mean - 0.044•Elevation_sd -11.148•Urban - 0.923•OtherLC - 8.194•Forest -11.135•Wetlands - 4.466•Agriculture + 0.928	0.9326	SE
2006 full	5.723•ΔUrban + 0.805•Elevation_sd (ln) + 0.435•Wetlands(ln) - 1.347•Slope_sd(ln) + 0.707	0.7751	SE
2006 buffer	9.952•Forest -5.883•ΔForest - 2.368•Elevation_mean(ln) + 0.712•Wetlands(ln) + 6.45•Other + 0.017•Elevation_sd + 0.431	0.9164	SE
TP			
1992 full	69.484•Wetlands + 0.18	0.4652	SE
1992 buffer	0.057•Slope_std (ln)+21.001•Wetlands + 0.15	0.5028	SL
2001 full	0.058•Urban + 0.026	0.7553	SL
2001 buffer	0.043•Elevation_mean (ln) - 0.162•Agriculture + 0.028	0.7191	SL
2006 full	0.506•Agriculture+ 0.405•Urban + 0.429•Forest - 0.250•ΔForest + 0.016	0.8674	SE
2006 buffer	0.001•Elevation_sd - 0.015•Wetlands(ln) + 0.271•Forest + 0.252•Agriculture - 0.126•ΔForest - 0.001•Slope_mean + 0.141•Urban - 0.016	0.8661	SE
WT			
1992 full	16.4556•Agriculture + 14.75•Urban + 1.398•Elevation_sd(ln) + 2.2	0.7150	SE
1992 buffer	-0.058•Elevation + 46.245•OtherLC + 0.034•Slope_mean + 2.092	0.7423	SL
2001 full	9553•Urban + 11.891•Agriculture + 1.173•Slope_sd(ln) + 1.583	0.9304	SL
2001 buffer	5.384•Elevation_mean (ln) - 0.071•Elevation_sd + 0.016•Slope_mean - 9.373•Forest -12.489•Wetlands -6.541•Urban + 1.223	0.9585	SE
2006 full	13.059•Agriculture + 8.607•Urban + 1.336	0.4697	SL
2006 buffer	-17.622•Other - 10.438•Forest - 0.123•Slope_sd - 12.542•Agriculture + 5.081•Urban + 1.199	0.8491	SL
TSS			
1992 full	982.738• Wetlands - 0.047•Slope_mean + 1.766•Elevation_sd(ln) - 0.023•Elevation_mean + 1.517	0.7834	SE
1992 buffer	1.834•Elevation_sd(ln) – 0.044•Slope_mean + 1.664	0.7393	SL
2001 full	8.548•Agriculture +0.046•Elevation_mean + 2.299	0.7240	SE
2001 buffer	no significant regressors		
2006 full	0.736•Slope_mean + 39.832	0.5951	SE
2006 buffer	-79.91•ΔUrban + 1.4•Slope_mean - 0.240•Elevation_sd + 13.825	0.9512	SE

SE = Spatial error model; SL= Spatial lag model
full= sub-watershed scale, OtherLC= other land cover; (ln)- the natural log was taken for this parameter; Δ- represents the change in a particular land cover type

DO is significantly associated with slope and stream order in 1992, then only slope in 2001, in 2006, urban and forest land cover variables were significant. This shift is probably due to the cumulative change that land cover has on aquatic life (Alberti et al. 2007). In 2006 the negative relationship between DO and percent urban area further supports the idea that urbanization is leading to loss of aeration and photosynthetic activity in the stream with removed riparian vegetation (Uriate et al. 2007). Unexpectedly, change in forest cover is also negatively related to DO. One would expect that as forest cover is lost stream temperatures would decrease, which leads to decreased DO (Allan, Erickson, and Fay 1997). This may be another case in which there is lag time between the change and result. This relationship is best explained by other factors that may be contributing to losses or gains of forested areas and further investigation is warranted.

TP shows a lot of variation from year to year. Percent urban area was positively associated with TP in 2001 and 2006, while percent agricultural area was only significant in 2001. Both of these land covers are expected to increase nutrient rich runoff from either lawn or agricultural fertilizers (Buck et al. 2004). The omission of agricultural area as a good predictor of explaining TP variations in the later year suggests that some best management practices may be controlling agricultural runoff and no longer predict TP variation. For example, the installation of riparian buffer strips could mitigate nonpoint source runoff in some parts of the Tualatin (Psaris and Chang 2014). Wetlands showed a positive regression with TP in 1992 and 2001, but not in 2006.

3.3 Relationship between land cover and water quality at two different spatial scales

WT shows the most variation between years and spatial scales (Table 4). In 1992 percent forest area was a significant variable at the sub-watershed scale but not at the buffer scale; elevation and stream order were significant at the buffer scale but not at the sub-watershed scale. In 2001 however stream order and percent urban area were significant at the sub-watershed scale, but neither was significant at the buffer scale. In 2001 the buffer scale was significant with elevation, slope and stream density for WT. Then in 2006, change in forested area was significant at the sub-watershed scale, but not as expected, and not at the buffer scale. This suggests that even if forest covers increased in the whole sub-watershed, if riparian areas do not have much vegetation or lost vegetation, water temperature could still increase. Previous studies show that riparian vegetated surface is critical to lowing stream temperature (Chang and Psaris 2013).

However, stream order, percent urban area and drainage density were all significant. The positive relationship between water temperature and stream density is expected since a higher volume of water per unit area or additional groundwater input can decrease water temperature. The scalar differences opposes the results from Pratt and Chang (2012) where the sub-water shed scale had more significant predictors than the riparian buffer scale. This discrepancy could be due to the fact that Pratt and Chang (2012) used a 50-meter buffer. The 100-meter buffer is more likely to reveal actual patterns in land cover since the resolution of the NLCD land cover layer is 30 meters by 30 meters. By changing the spatial resolution of land cover map, one could potentially obtain a different quantification of water quality estimates in the riparian buffer area (Baker et al. 2007).

Conversely, TSS showed the least variation between scales. Slope was a significant predictor at each time period and scale. In 1992 percent urban area was also significant at both scales, and in the 2006 drainage density was significant at both scales. This suggests that TSS in streams is generated from both distant (watershed wide) and near (e.g., stream bank or bed) sources. Our finding is somewhat comparable from Uriate et al. (2011) who found that turbidity, which could be used as a proxy for TSS, responded more to the land cover in large scale watersheds than it did at smaller scales. The land cover of the entire watershed should be contributing to the particulate matter in the stream. However, TSS is also likely to be affected by the land cover in its immediate vicinity. This is highlighted by the fact that mean slope is the sole parameter that is significantly positively correlated with TSS at every scale. This suggests that runoff is a large contributing factor to the amount of TSS in the stream and therefore the land cover close to the stream will also have an influence on what enters the stream.

DO has the least variation between the two scales. Since DO is the amount of water aeration, it is also affected by runoff velocity and volume. This is evident in 1992 and 2001 where there are any differences in significant parameters and mean slope is the largest predictor of DO at both scales. In 2006 there is more variation and the land cover variables are found to be significant. Percent urban area and change in forested area are significant at both scales, as these land covers are related to the amount of impervious surface, which is a large contributing factor to runoff. However, the other land cover and drainage density is significant at the buffer scale, explaining up to 73% of variation. This is somewhat different from previous studies that found DO responding more to the larger watershed processes than riparian processes (Uriate et al. 2011). More work would need to be conducted classifying other land covers to detect what DO could be responding to.

Finally, TP shows a lot of variation by scale. In 1992 only percent wetlands is significant and positively related to TP at the buffer scale, likely holding the phosphorus that is located in the soils in the Tualatin River Basin (Boeder and Chang 2008). In 2001 and 2006 percent urban area is positively associated with TP at the sub-watershed scale, but not at the riparian scale, suggesting that human activities from urban area are likely contributing to an increase in TP at the sub-watershed scale (Pratt and Chang 2012, Scott et al. 2002, Uriate et al. 2007). TP also responds to an increase in drainage density at the sub-watershed scale, suggesting that it is easily transported from upstream areas. At the buffer scale, percent other land cover has a significant negative relationship with TP in 2001 and 2006. This suggests the more cumulative effects of land cover and drainage density on TP over a watershed area in a stream being stronger than the effects of land cover in the immediate area. Since land cover is not related to TP at the buffer scale, closer attention should be paid to shrubs and herbaceous land cover as a predictor for TP at this scale because it is likely that shrubbery and herbaceous land covers are acting as filters of TP.

4. CONCLUSIONS

This study indicated that water quality in already urbanized streams did not change significantly during the 20-year period, while water temperature increased in streams that are in the process of urbanizing. Other water quality parameters did not show strong results. This indicates that the response of water temperature to urban development might be quicker than the response of other water quality parameters to urban development. The delayed response of other water quality parameters also suggests that other watershed environmental variables (e.g., slope, and drainage density) other than land cover change might be responsible for explaining the variations in changes in water quality.

The relationship between land cover and water quality has changed over the three periods representing the early-1990s, the early-2000s, and the mid-2000s. The relative importance of independent variables in explaining the variations in water quality also changed across different scales. At the sub-watershed scale, land cover variables are generally more important, while at the 100m buffer scale, topographic variables become significant in explaining the variations in water temperature and TP. DO is mostly explained by mean slope in 1992 and 2001 at both scales, but urban land cover became an important predictor in 2006 at both scales. The surprising influence of forest land cover change on WT and DO suggests that potential lag time is required to see the effect of reforestation, including riparian restoration.

Future research should consider the effect of the city's pipe network, especially in heavily urbanized areas, because storm runoff may be redirected from the natural watershed to other points in the stream, causing potential discrepancies in the results. In other words, when a heavy pipe network is present and storm pipes drain water near monitoring station, riparian restoration may not function as expected because stormwater can bypass riparian areas. This is particularly the case in the old developed areas such as Fanno Creek, a tributary of Tualatin River and Burnt Bridge Creek. A detailed field investigation is required to detect the size of storm drain pipes in riparian areas. Additionally, our data is based on grab samples, so water quality measurements may have been influenced by different meteorological conditions. This necessitates a long-term continuous monitoring of water quality and land management practices to detect long-term trend in water quality.

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