THE INFLUENCE OF LAND USE ON LOWLAND STREAMS IN THE PUGET SOUND:

A CASE STUDY FROM CARPENTER CREEK

by

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ABSTRACT

The influence of land use on lowland streams in Puget Sound:
A case study from Carpenter Creek

Fawn Trey Harris

Human activities and land use, including urbanization has degraded water quality and habitats throughout the world. The small streams of the Puget Sound are increasingly threatened by urbanization as the population in the Puget Sound expands. This research investigates land use and spatial and temporal variation in water chemistry relationships within Carpenter Creek, in the Puget Sound Basin of Washington State.

The physiography of stream sampling sites were found to be homogenous in several landscape metrics, and therefore this study was unable to discern specific relationships between water chemistry parameters and landscape metrics. An ANOVA revealed significant seasonal differences in several water chemistry parameters, providing a baseline for seasonal variation in water chemistry parameters for Puget Sound lowland streams.

An ANOVA and Tukey's Post Hoc test found significant differences in fecal coliform contamination between seasons at each site, with the significant increases occurring during the summer season. Fecal coliform means for the summer season exceeds the maximum concentration for Washington State surface waters in salmon bearing streams. This trend was observed during the dry season which contradicts current literature and implies a possible underrepresented pollution pathway. The growing rates of urbanization within the Puget Sound lowland, pose significant threats to endangered and threatened salmonid species which rely on these habitats to complete their life history strategies. Understanding how these land uses affect water quality can provide important information for habitat managers.

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Introduction

Our waterways and their biotic communities are in peril due to increasing urbanization and anthropogenic land use change. There is a substantial body of literature documenting that watershed urbanization is associated with substantial alterations in flow patterns, channel morphology, water quality, and biotic communities (Sun and Lockaby 2012, Ding et al. 2016, Bunn and Arthington 2002, Booth 2004, May 1997, Lenat and Crawford 1994, Poff et al. 1992). The small streams of the Puget Sound have been especially affected by land use alteration and urbanization (May 1997, Morley and Karr 2002, Booth et al. 2005). However, the relationships between urbanization and water quality in these streams are relatively understudied. As urban landscapes continue to expand, it will be increasingly important to understand how these urban water systems function. With forecasts of increasing population and changes in precipitation resulting from climate change, the relationships between land use and water quality will likely take on increasing importance and need further exploration.

Human land use change can affect the physical and chemical properties of nearby aquatic habitat, by altering the groundwater exchange with surface water (Sun and Lockaby 2012, Allan and Castillo 2007, Hayashi and Rodenberry 2002). Land use change is often associated with the replacement of natural vegetation with impervious surfaces, reduction in transpiration and filtration within the drainage basin, and increases in urban runoff frequency and intensity (Sun and Lockaby 2012, Allan and Castillo 2007). There are several mechanisms through which land use can affect water quality including: sedimentation, nutrient enrichment, contaminant pollution, hydrological alteration, and riparian clearing/canopy opening (Allan 2004). Urbanization exacerbates these mechanisms and plays a significant role in decreasing the water quality of urban streams. Exploring the relationships that influence these mechanisms will prove beneficial to the restoration of degraded urban streams.

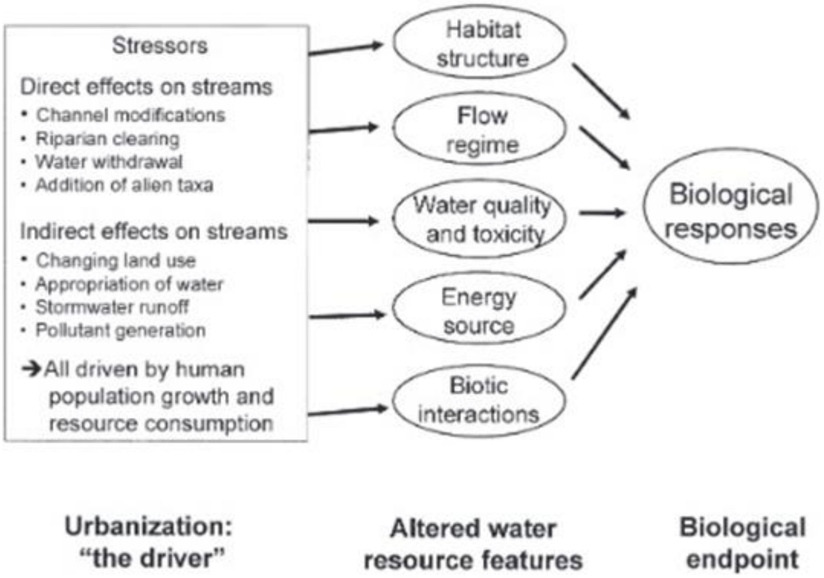

Figure 1 Conceptual model of anthropogenic stream stressors. From Booth et al. 2004.

Poff et al. (1997) describes how flow regime influences water quality, energy sources, physical habitat, and biotic interactions and therefore influences the ecological integrity of the system. Water quality and quantity is extremely important to the life history strategies of many aquatic organisms. Several aquatic species use water chemistry indicators to trigger different life cycle events. For example, streamflow plays a significant role in the life history strategies of many fishes (Booth 2004), with life history strategies linked directly to flow regimes (e.g. phenology of reproduction, spawning behavior, larval survival) (Welcomme 1985; Junk et al. 1989; Copp 1989, 1990; Sparks 1995, Humphries et al. 1999 as referenced by Bunn and Arthington 2004). Therefore, any alteration in the natural flow regime could dramatically impact the health and survival of some fish species. Salmon species are especially susceptible to changes or fluctuations in certain water quality parameters such as temperature (Carter 2008). Over the last several decades, salmonid populations in the Pacific Northwest have been declining due to the cumulative effects of land use practices, agriculture and urbanization (May 1997). Studying these land use practices and their relationships to water quality parameters is an important step in beginning to restore these salmon populations and their habitats.

The most common effect of urbanization within a river catchment is alteration of the hydrological flows (Sun and Caudwell 2015, Sun and Lockaby 2014). Urban areas within river catchments can alter the river’s hydrology through sediment deposition, erosion, alteration in evapotranspiration, alteration of interflow, and groundwater permeability (Figure 2). Impervious surfaces and loss of natural ground cover significantly alter the landscape, and disrupt natural hydrologic interactions. The amount of imperious surface in urban areas is a primary contributor to the alteration of flow characteristics in urban streams. Roads, rooftops, and lawns are all impervious surfaces and increase the transportation of pollutants into water systems.

Structures constructed in-stream (e.g., dams, culverts, weirs, ladders) and along riparian habitats effect the flow of water and the movement of energy within the system. In the Puget Sound, anthropogenic changes to in-stream habitat have created a habitat which is very different from the habitat where the aquatic species evolved (May 1997), hereby making it more and more difficult for endangered and threatened species to recover. The increasing urbanization within Puget Sound lowland streams, will continue to alter the natural flow regime and the biological integrity of the stream.

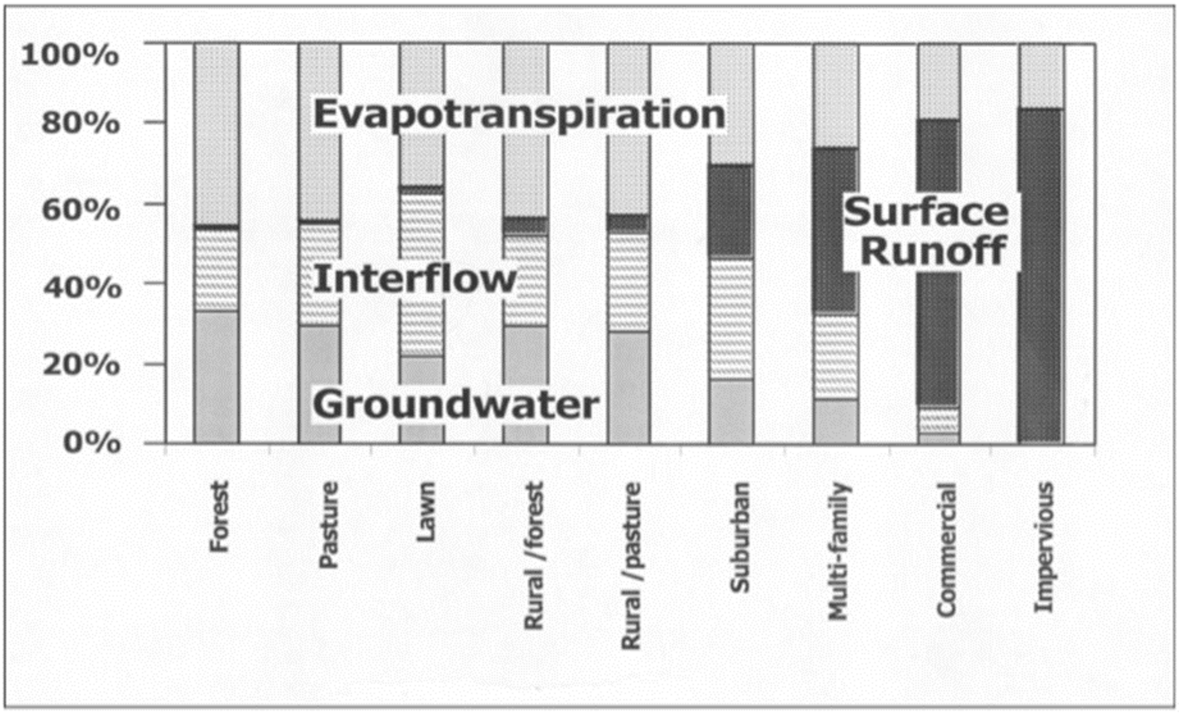

Figure 2 Changes in the ratio of groundwater, interflow, evapotranspiration, and surface runoff based on land cover in Western Washington. From Sheldon et al. 2005)

Nutrient enrichment and pollutant contamination are also common in urban streams. It is well documented that nutrient enrichment is associated with agricultural land use, human activities, and waste systems. Urban areas contribute to physical and chemical pollutant contamination which severely stresses the biological integrity of surrounding stream systems. Road way runoff and runoff from impervious surfaces are the primary pathways for nutrients (e.g. nitrogen, phosphorous, organic material) and pollutants (e.g. inorganic compounds, heavy metals, bacteria) to contaminate a stream system. Studies have shown that Washington State has higher highway runoff rates than the national average (Herrera Consultants 2007). Although research has shown that the land use type is a direct contributor to nutrient and chemical pollution (Neilsen et al.

2012) there is little research exploring these relationships in Pacific Northwest lowland streams.

With forecasts of a changing precipitation and its seasonality with climate change (Pachauri et al. 2014), understanding land use and water quality relationships will be extremely important to providing the best available science to policy makers and natural resource managers. The future of Puget Sound stream systems and salmonid populations depend on a thorough understanding of the mechanisms affecting water quality in lowland streams. This research intends to; build on current literature about land use/water quality relationships in small order streams, provide information about urbanization effects on water quality in urban streams, provide insight to current restoration managers actively working on the site, and build upon existing literature on Puget Sound lowland streams.

Literature Review

Land use change and water quality

Growing urbanization in the Pacific Northwest threatens the health of many urban watersheds and the health of the associated biological communities. Human population growth in the Pacific Northwest carries a host of environmental threats; including imperviousness, urban sprawl, contaminants, pollution pathways and the modification of stream and riparian habitats. Urbanization can have several effects on watersheds such as; the alteration of natural hydrology, loss of riparian habitat, and the alteration of water chemistry. In the Puget Sound lowland ecoregion, small streams and associated wetlands are the ecosystems most effected by urbanization (May 1997). Many of these ecosystems are critical habitat for migrating, rearing, and spawning salmonids (May 1997), as well as with important habitat for several other Pacific Northwest species. Understanding how different land uses affect water chemistry parameters can help better inform natural resource managers and urban planners to prepare for environmental resilience when facing climate change.

Most land use changes have the potential to affect the structure and function of surrounding aquatic ecosystems, floodplains, and watersheds (Ecology 2015, Allan and Castillo 2007, Poff et al. 1997, Naiman et al. 1999, Allan and Castillo 2007). Land use changes, rather than in-stream structures, are the primary cause of alteration in the natural flow regime due to changes in sediment delivery, decreases in soil infiltration, and increased runoff (Poff et al. 1997). Land use changes not only negatively alter the natural hydrology and water chemistry, but they can also alter the life processes of several aquatic organisms. Some organisms, such as salmonid species, are extremely susceptible to changes in water quality.

Stream systems are largely affected by disturbances within their watersheds, whether or not the disturbance occurs in close proximity of the stream. There are several mechanisms through which land use can affect stream habitat and water quality. Allan (2004) has grouped these mechanisms into the following categories: sedimentation, nutrient enrichment, contaminant pollution, hydrological alteration, riparian clearing/canopy opening and loss of woody debris. Of the water quality parameters effected by land use, this research plans to examine fecal coliform, nutrient cycling, temperature and streamflow. The water quality parameters selected for this study are significant to aquatic biota, ecosystem functioning, and human health. Understanding how these parameters are affected by different land uses can assist planners and scientists in preparing these local systems for ecological resilience in the face of climate change.

Mechanisms of land use influence on water quality

Sedimentation

Sedimentation is a natural occurrence in aquatic systems, but increases or decreases in the natural sediment load can affect the physical attributes of the system and the lifecycles of the aquatic biota. The movement of sediment through an aquatic system is essential to the formation of channel morphology and creation of substrate. Sedimentation is critical for the healthy ecological functioning of aquatic and terrestrial communities near stream and river systems (Naiman et al. 1992). Land use change poses significant threats to a stream's natural flow regime and associated biota due to alteration in the sediment flows and transport (Poff et al. 1997). Urbanization and land use change pose significant threats to the natural flow regime and the water quality within an aquatic system.

Sediment movement and accumulation plays a large role in the presence and concentration of certain pollutants in surface water. Many pollutants tend to bind with fine particulate material, organic matter, and sediments; allowing for easy transport of the pollutants throughout an aquatic system (May 2009). Because of their low solubility in water, Polycyclic Aromatic Hydrocarbons (PAHs) and many organic compounds are transported to water systems during high intensity rainfall events and other storm water events (Herrera 2007). Similar to organic compounds, bacteria and nutrient concentrations are also commonly associated with sediments due to their ability to bind to sediments (Herrera, 2007). Alteration and removal of natural vegetation communities and forest stands also increases the sedimentation to the watershed (Sun and Caudwell 2015) and reduces soil infiltration (Poff et al. 1997). Increases in pollutants due to growing urbanization and alteration of sedimentation regimes, poses significant threats to the biodiversity within urban stream systems.

Sedimentation plays a large role in the structure and function of stream systems, and growing urbanization increases the risk of sedimentation instability and the likelihood of pollutant transport. Sediment is often associated with pollution due to the ability to work as a transport service for organic materials. The concentration of sediment in the water column and size of sediments can have direct effects on water quality parameters including; lowering the dissolved oxygen content, increasing temperature, increasing turbidity, altering the nutrient cycle and streamflow (Sun and Cauldwell 2015, Sun and Lockaby 2012, May 1997, Poff et al. 1997). Urban imperviousness increases sedimentation deposits and subsequent pollution loads, creating a significant need for growing the wealth of knowledge pertaining to urban land use-water quality relationships.

Nutrient Enrichment

There are several environmental and anthropogenic pathways in which nutrients can enter aquatic systems. Environmental nutrient pathways include atmospheric deposition, organic matter decomposition, groundwater, and soil inputs (Allan and Castillo 2007). Anthropogenic land use change can create additional nutrient pathways through the modification of riparian habitats, extension of impervious surface, clear cutting, stream modification and urban development (Sun and Lockaby 2012, Allan and Castillo 2007, Booth 2004). Nitrogen in watershed catchments has been positively correlated with agriculture and urban lands, and negatively correlated with increasing forest cover (Allan and Castillo 2007). Increasing the abundance and density of agriculture and urban areas is expected to increase the nutrient concentrations of nearby streams and watersheds.

Nutrients are an increasing concern to aquatic ecosystems, due to their ability to stimulate plant and algal growth. Eutrophication and hypoxia can occur when the dissolved oxygen content in water has been compromised due to excessive algal growth. Nutrients are usually measured in ammonium nitrate, nitrate, nitrite, total Kjedahl nitrogen, and total nitrogen (Herrera Consultants 2007). Many aquatic organisms are adversely affected by high nutrient concentrations and low dissolved oxygen levels. In recent years, the Puget Sound has seen significant increases in the frequency and severity of hypoxic events along shorelines and estuaries (Ecology 2017). As the climate in the Puget Sound continues to change, it will be become increasingly important that scientists understand the sources of pollution and their effects on surrounding watersheds.

Understanding the influences of urbanization and land use on nutrient pollution can assist urban planners and restoration scientists to prepare for resilience in a time of climatic change.

Contaminant Pollution

Runoff from impervious surfaces is a large pollution pathway, serving as a transport vector for agricultural fertilizers, atmospheric deposition and nitrogen from car exhaust (Herrera Consultants 2007). Impervious surfaces are described here as, “anthropogenic land use change that have resulted in impermeable land cover (e.g. rooftops, road ways, and lawns)”. Impervious surfaces allow for chemicals and nutrients to gather and be washed into surrounding watersheds with rainfall and first flush events (Allan and Castillo 2007, Allan 2004). Increasing urbanization in watersheds often has negative effects on freshwater biota through the anthropogenic development of natural habitat into impervious surface and the introduction of pollution pathways. As land cover increases to greater than 50% imperviousness, the biological integrity and water chemistry of streams becomes highly compromised (May 1997). The higher than average nutrient levels and growing urbanization in western Washington indicate a need for thorough understanding of these local systems. The unique geomorphology of the Puget Sound region, implies an urgent need for more research on these relationships in Puget Sound lowland streams.

In addition to runoff containing high levels of nutrients, organic compounds, and metals; it also serves as a pathway for bacterial infections to enter water systems. Measuring fecal coliform bacteria can help assess the risk of a water body to a bacteriological contamination. Fecal coliform bacteria are not directly harmful to humans but is used an indicator of potential fecal contamination (Herrera Consultants 2007).

Urban streams tend to have elevated levels of fecal coliform and *e. coli*. bacteria compared to their non-urban counterparts (Sun and Lockaby 2015). High levels of fecal coliform have been positively correlated with the presence of pathogens which are known to cause human illness (KCHD 2015). In Kitsap County, point and non-point sources of fecal coliform bacteria come from failing septic systems, combined sewer systems, agricultural waste, food waste and storm water drainage pipes (KCHD 2015). Runoff and chemical contaminants are a serious problem in Puget Sound urban streams, with little research available about the different land use variables and their effects on different water quality parameters.

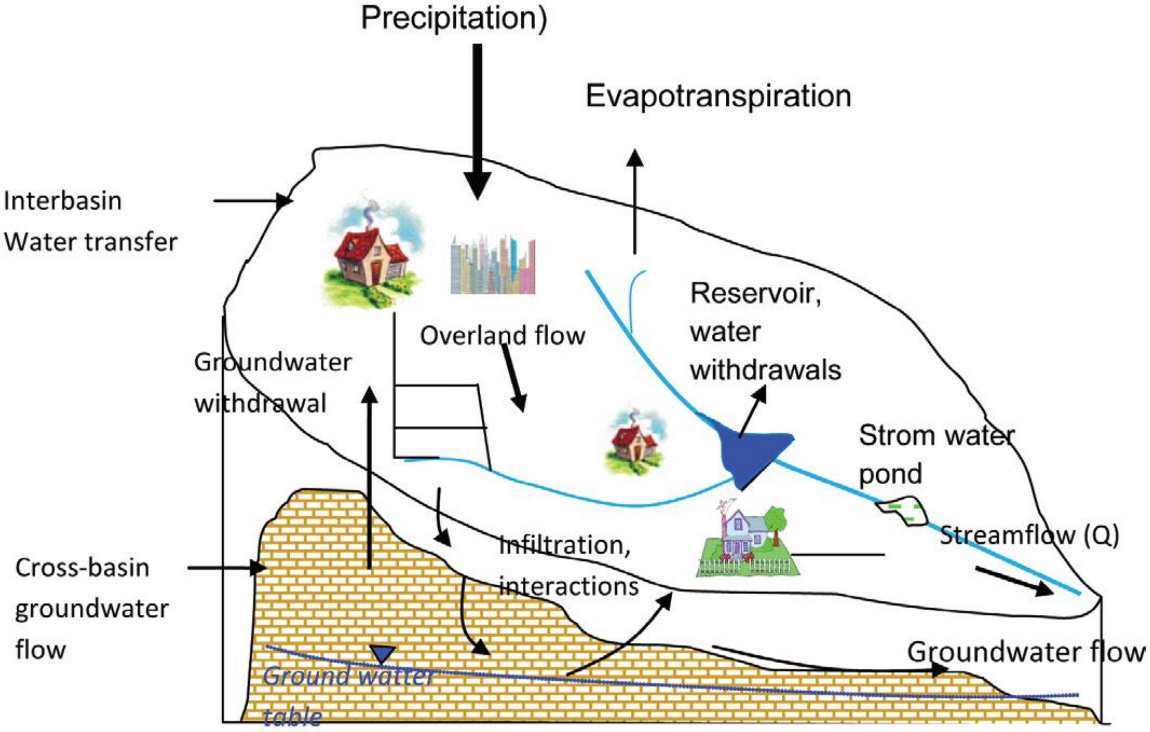

Figure 3 Water cycle within an urbanized watershed. From Sun and Lockaby (2012).

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Hydrologic Alteration

Land use change within and near streams can have severe effects on a stream's natural flow regime. The primary land use activities that can affect the natural flow regime include timber harvest, agriculture, urbanization, and livestock (Poff et al. 1997). Many watersheds in the Puget Sound region have experienced many, if not all, of these land use activities throughout the last several hundred years. Any alteration to these stream conditions can potentially alter the stream's hydrogeology causing severe long-term effects such as erosion, deposition, and flooding. Alteration of the hydrological regime can also affect the ability of aquatic organisms to establish or may affect the overall composition of existing habitat.

Streamflow is essential to many of the stream's characteristics and plays an important role in the life history strategies of several aquatic organisms. Streamflow is variable and differs widely based on location and several other contributing factors. The quantity, timing, and temporal patterns of streamflow are extremely variable and influence the physical, biological, and chemical conditions of the stream (Allan and Castillo 2007). Flow is ultimately derived from precipitation and influenced by climate, geography, soil type, topography, and vegetation (Poff et al. 1997). Climate change and projected urbanization increases are expected to have several effects on streamflow of Puget Sound urban streams. Morley and Karr (2002) found significantly lower biological integrity in urban streams that experienced a high degree of flow flashiness. Analyzing the relationships between land use and streamflow in low order urban streams could be essential in preparing these systems for ecological resilience for climate change.

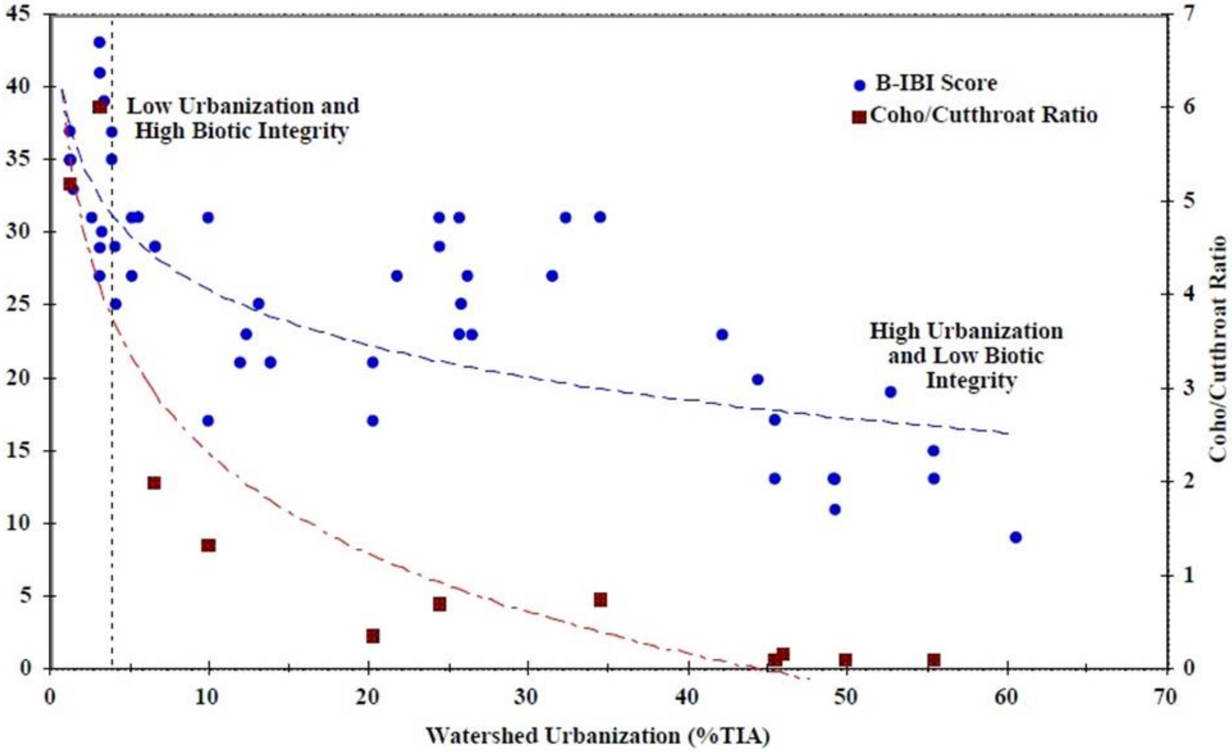


Figure 4 Relationship between watershed urbanization (%TIA) and biological integrity in Puget Sound lowland (PSL) streams. The benthic index of biotic integrity (B-IBI) and the abundance ratio of juvenile coho salmon to cutthroat trout were used as indices of biological integrity. From May 1997.

Riparian Clearing/Canopy Opening

Healthy and intact riparian areas are extremely important to the structure and function of all stream and river systems. The quality of the riparian habitat is essential for the healthy functioning of a stream ecosystem (Wang 2001). The alteration of riparian habitat has the ability to alter stream temperature, quantity and character of dissolved organic carbon reaching the stream, sedimentation, shade availability and bank stability (Allan 2004). Any alteration in the riparian corridor has great potential to negatively impact stream water chemistry.

Many land use changes near streams are associated with riparian clearing and canopy opening. Clearing riparian vegetation and opening the canopy creates a pathway for light energy to reach the stream, subsequently reducing shade and increasing temperature (Allan 2004). Increases in temperature may influence the growth of harmful algal blooms. In addition to the temperature effects, riparian clearing is linked to erosion and sedimentation which can alter dissolved oxygen content and the concentration of pollutants (Allan 2004). Removing native riparian plant species may also effect the riparian zone's ability to filter harmful contaminants and pollutants from storm water runoff before entering the stream.

Although riparian areas effect water quality, several studies have found that the influence of land use extends much further than the riparian area (Utz et al 2016, Nielsen et al. 2012, Pratt and Cheng 2012, Morley and Karr 2002). Booth et al. (2014) found that percent urbanization in the watershed is not the most important factor influencing temperature in urban streams of Puget Sound, but that many factors such as canopy cover, contribute to the overall stream temperatures. The work of Booth et al. (2014) and others illustrate the need for more research on land use effects on water quality. Understanding land use effects at multiple scales may help better inform water resource managers on the scale and intensity of land use-water quality relationships.

Land use-water quality relationships and climate change

Urban development in the Puget Sound has increased drastically in the last several decades with populations continuing to grow. Growing urbanization, coupled with climate change, is expected to further alter the water chemistry from baseline values, posing threats to aquatic habitats and organisms. Changes in climate (precipitation and temperature) are expected to adversely impact surface water chemistry (Murdock et al. 2000). Increased risk of drought and changes in precipitation patterns are expected to increase the effects of urbanization on water quality (Sun and Caudwell 2015). Due to these expected outcomes, it is increasingly important for water quality and land use relationships to be studied, especially in areas with unique topography such as the Puget Sound.

Current literature examining land use and water quality

Previous applications

While many of the mechanisms of how water quality might be affected by land use have been investigated, the specific relationships that exist between land use and water quality parameters remain understudied. The existing literature on land use and its effect on water quality parameters have been limited in temporal and spatial scope. Relationships between agricultural land use and water quality are perhaps the most studied of all land use patterns. The effects of urbanization on water quality has also been well documented in recent years. However, many researchers describe a need for more research investigating these relationships at multiple spatial and temporal scales, as well as in diverse geomorphic conditions.

Agricultural land use and its relationship to water quality parameters has been commonly studied and has been attributed to increased nutrient levels in nearby watersheds (Lenat and Crawford 1994, Allan and Castillo 2007, Nielsen et al. 2012, Ding et al. 2016). Nitrogen and phosphorous concentrations have been associated with fertilizers and animal waste from agricultural areas (Allan and Castillo 2007). The development of agriculture land in watersheds provides many non-point pollution sources of nutrients to the aquatic habitats (Allan 2004). Ding et al. (2016) found that poor, water quality was associated with high patch densities of cropland, orchards, and agriculture. Agricultural areas are also associated with poor lentic habitat quality (Allan 2004) and lower invertebrate species diversity (Lenat and Crawford 1994). Although there have been a few studies examining the relationships between agricultural land use and water quality, most of these studies are limited to a specific geographic region or their sampling methods are limited.

Urbanization, usually defined as areas of impervious surfaces, has been linked to many different effects on water quality. The health of a stream has been directly correlated to the percentage of impervious surfaces within a catchment (Alberti et al. 2007, Morley and Karr 2002, Arnold and Gibbons 1996). Impervious surfaces influence the frequency and amount of pollution reaching aquatic systems (Utz et al. n.d.). Utz et al. (n.d.) describes that impervious surface is a fundamental landscape stressor. Storm water pollution is of interest in urban areas, and some studies have noted urbanization’s contributions to storm water pollution. Storm water is often linked to increased nutrients, sedimentation, and heavy metals in surrounding watersheds (McCarthy et al. 2008, May 1999). Many aspects of urbanization influence the flow and movement of pollutants into a water system through the creation of new pollution pathways and creating new sources of pollution.

Past and present land uses have been found to affect stream health (Maloney and Weller 2011). Yu et al. (2013) performed statistical and spatial analyses with water quality and land use data collected from Shenzhen watershed in China, and found strong correlations between increasing urbanization coverage and decreasing water quality. The

Puget Sound is a mosaic of small streams and rivers, increasing urbanization in these areas is expected to have direct effects on the water quality in nearby watersheds. Understanding how these relationships effect different types of streams with different geomorphic conditions is important to the future of water quality issues.

Some research from the Puget Sound region has looked at the biological integrity of urban streams by sampling for benthic invertebrates (Morley and Karr 2002, Alberti et al. 2007). Both studies used benthic invertebrate sampling and the Benthic Index of Biological Integrity (B-IBI) to characterize the effect of land use on stream water quality. Trends in this research found that biological integrity decreases as urbanization increases, but water chemistry parameters were not sampled in these studies. Morley and Karr (2002) did measure stream flow, and found B-IBI to be correlated with flow fluctuation. Although these studies are useful in understanding the extent of urbanization effects on stream biota in the Pacific Northwest, the results do not provide information regarding water quality and land use relationships.

Many studies in the existing literature utilize Geographic Information Science (GIS) and water quality data to spatially analyze land use and water quality relationships. Tu et al. (2011) studied the relationship between impervious surface density and percentage of land use type to water quality parameters. The results of Tu et al. (2011) found that the impact of land use on water quality differed between parameter and the level of urbanization in the watershed. Because of the various environmental factors that can influence water quality, site specific information is important to local agencies and scientists.

River and stream systems are very diverse in biological, chemical, and physical characteristics. Because each stream and watershed has several unique attributes, it is often difficult to extrapolate data from one stream and apply it to another, even if several physical factors are similar (e.g. catchment size, drainage areas, land use type). With this respect, it may also be difficult to compare a stream to a reference stream due to the unique watershed characteristics of individual streams. Researchers suggest that some of the variability in water quality measurements is based on the geomorphic features of a particular watershed (Yu et al. 2013, Ding et al. 2016). Due to the range of geomorphic variability and its influence on land use-water quality relationships, it is important to study these relationships over a wide range of geomorphic types and features. This research looks to explore the land use-water quality relationships in Puget Sound lowland streams, a very understudied system, the Kitsap Peninsula.

Limitations

Although land use and water quality relationships have been of interest to many researchers for the past several decades, there are several limitations to the existing studies. Many studies are restricted to a specific geographical region or place in time, which may or may not be relevant to the Pacific Northwest. In the existing literature, several studies lack large sets of water quality sampling data or use short or snapshot sampling events. Much of the time, the lack of sampling data is directly related to the lack of funding for monitoring. Unfortunately, this can lead to the failure to recognize trends in the data (Type I Error). Large datasets over a long temporal scale are the most efficient way to study land use-water quality relationships.

A recent study by Ding et al. (2016), examined land-use and water quality parameters from multiple spatial locations but from only one point in time. Another recent study in Shenzhen, China used statistical and spatial analyses to examine land use and water quality (Yu et al. 2013), but the study was again limited in the amount of data collected. The data collected for Shenzhen was limited to a two-year period, which can lead to analysis errors by failing to recognize seasonal and climatic relationships. Two years is a relatively small amount of time to notice trends in data, especially when water quality can be affected by seasonal climate changes.

Another limitation in the current literature is the origin of the data and the method of collection used by several studies. To promote accuracy and precision, the water quality collection methods and analysis should be the same at each sampling location. A study conducted by Pratt and Chang (2012), used water quality data collected by multiple agencies, each using a different collection methods and protocols. Haidary et al. (2013) examined differences in water quality parameters between different land uses but used 24 different wetlands for the study, all of which could have different pollution pathways and pollution influences. Each wetland has its own unique geomorphology which influences certain water quality parameters either directly or indirectly. Comparing land use-water quality relationships from multiple spatial locations is not as accurate as comparing land use-water quality relationships from the same spatial location over a period of time. The most effective way to assess relationships at the land-water interface, is to monitor parameters over a long temporal range in the same spatial location.

One study, Zhou et al. (2012), collected an impressive 18 years of data to examine land use and water quality data for the Dongjiang River. While this study provides useful insight into the scale of land use patterns and their relationships to water quality, the researchers averaged and clumped the water quality data into time periods lasting several years. In an effort to mitigate the effect of precipitation on flow and water quality, the researchers choose to examine parameters collected during the dry season only (Zhou et al. 2012). Analyzing parameters collected during the dry season and negating those collected during the wet season fails to identify several relationships that might exist seasonally, or even worse, may fail to identify much larger data trends. Zhou et al. 2012 grouped data into multiple year periods, completely failing to examine the relationships that might exist with season or year. There are several factors that must be accounted for when attempting to analyze parameters influenced by environmental trends. Considering that water quality is influenced by biological, chemical, environmental, and physical factors; it is pertinent that these mechanisms be investigated in their entirety.

Another limitation in the current literature, is the lack of existing research on low order streams. Low order streams-first and second order streams- play significant roles in aquatic ecosystems yet their importance is often overlooked in research. Although small in size, low order streams provide the same ecosystem services as larger streams and rivers. Low order streams are highly susceptible to land-use disturbances because they are highly interconnected to the surrounding landscape (Freeman et al. 2007 as referenced in Ding et al. 2016). Although low order streams make up a significant portion of the world's rivers and streams, there is very little existing research on low order streams (Ding et al. 2016). Currently, the only research on land use and water quality in low order streams was conducted in the monsoon ecosystems of China. Ding et al. (2016) discovered that water quality in low order streams is most affected by land use configuration. While Ding et al. (2016) found significant trends in their research, there is still a substantial need for more research on land use and water quality relationships in low order streams.

Of the reviewed research, only a few studies were found investigating water quality and/or land use and in the Puget Sound lowland streams (Luce et al. 2014, Shandas and Alberti 2008, Alberti et al. 2007). However, these studies were all from different geographical locations around the Puget Sound, with none from the Kitsap Peninsula. For example, Shandas and Alberti (2008), examined water quality and land use metrics in eight watersheds in the Puget Sound, and found that upland riparian habitat had a large influence on water quality. However, this study was conducted in streams on the western slopes of the Cascade mountains, which has very different topography than the Kitsap Peninsula. Luce et al. (2014), studied stream temperate variability in the Pacific Northwest, but again the sampling locations consisted of many mountainous streams and relatively few lowland streams. The locations of these streams have different environmental influences than streams on the Kitsap Peninsula and therefore the relationships between land use and water quality are possibly very different between geographical location. Many of the streams and rivers in Washington State originate from melting snowpack and glaciers, and the literature available reflects this, with little available research on groundwater fed streams in the Puget Sound.

The literature review found one study from the Kitsap Peninsula investigating stream water chemistry, however this study had very different parameters than those being examined here. Researchers from Stanford University, conducted a study investigating if herbicides, pharmaceuticals and personal care products had pathways to surface water other than septic systems. Dougherty et al. (2010) sampled creeks and groundwater in the Liberty Bay Watershed on the Kitsap Peninsula, and found that the specified compounds were being released into the environment by sources other than waste water. While this research is not investigating the same relationships, this study provides important information about the water chemistry influences to Kitsap Peninsula groundwater fed streams. In the Puget Sound, shorelines and areas with less than 50 feet above sea level have generally been found to be groundwater recharge aquifers (Vacarro et al. 1998 as referenced by Dougherty et al. 2010). It is possible that some water pollution sources in Puget Sound lowland streams are due to contamination of the groundwater recharge aquifers, perhaps this research may provide some insight into these mechanisms.

A review of the current literature suggests that there is a significant and pressing need for more research on land-use and water quality relationships, especially on the topographically and geographically unique, Kitsap Peninsula. While many researchers have found notable relationships existing between land use variables and water quality trends, many of these same researchers have expressed the spatial and temporal variance in the data and the need for more research. In the Puget Sound, much of the existing literature on land use and water quality is focused around storm water runoff and its effects on the salmonid populations. This literature review did not reveal any studies examining land use-water quality relationships Puget Sound lowland streams, with almost no research on Kitsap County low order streams. The current research describes that many variables influence water quality and therefore site specific information is often the most useful in understanding these relationships. This research will build upon existing literature and explore land use effects on water quality in an urban, Puget Sound lowland stream.

Methods

Study Site

Carpenter Creek is a 2.9-mile stream located within the Foulweather Bluff/Appletree Cove watershed in Kingston, Washington. The creek is a groundwater fed stream, originating at approximately 280 feet above sea level. Carpenter Creek is a second-order stream, joined by Trillium Creek approximately 210 m downstream from Carpenter Lake. The elevation of the stream decreases steadily from the headwaters to the mouth of the stream, with the largest declines near the headwaters. The primary soil type of the Carpenter Creek drainage basin was found to be advanced outwash, a highly permeable soil. The creek empties into Appletree Cove before draining into the Puget Sound. The total watershed encompasses an area of 1,886 acres (KPHD 2014) of the Kitsap Peninsula.

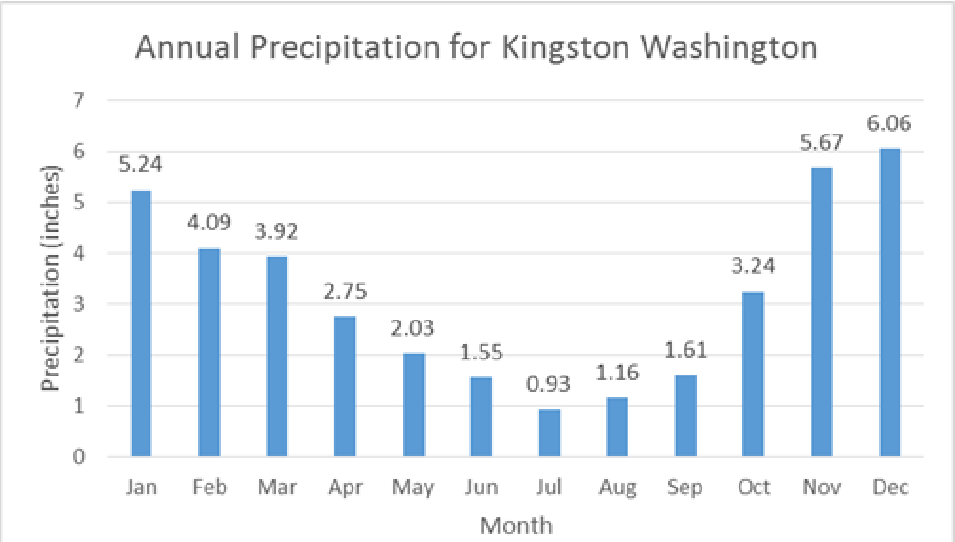


Figure 5 Annual Precipitation for Kingston, Washington. Data from *http://www.idcide.com/weather/wa/kingston.htm*

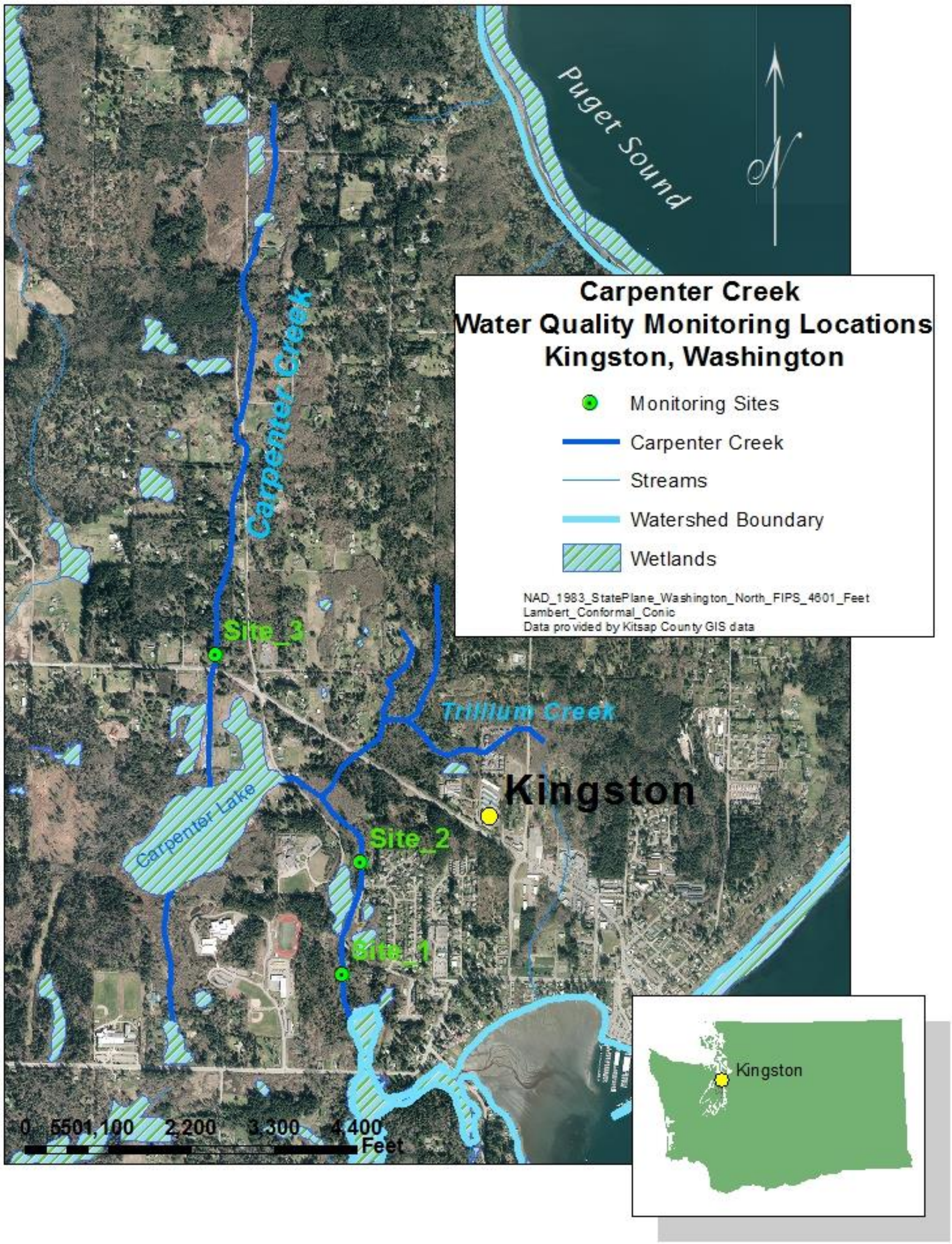


Figure 6 Aerial map of Carpenter Creek and the surrounding wetlands. Located on the Kitsap Peninsula in Kingston, Washington. Stillwaters Environmental Center Carpenter Creek water quality monitoring sites are illustrated.

Carpenter Creek and the Carpenter Creek estuary provides important habitat to migrating and rearing salmonids and forage fish. There are several salmonid species which utilize Carpenter Creek including: coho *(Oncorhynchus kisutch),* chum *(Oncorhynchus keta),* cutthroat trout *(Oncorhynchus clarkii),* and chinook *(Oncorhynchus tshawytscha)* (Azerrad 2012). Chinook is currently listed as a threatened species in the Puget Sound (UFWS 2015). Carpenter Creek falls under the WAC 173-201A-600, where any surface waters not listed on table 602-Carpenter is not listed- shall be, "protected for the designated uses of: Salmonid spawning, rearing, and migration. . ." and is also recognized and protected for uses as "Core summer salmonid habitat; and extraordinary primary contact recreation" (KPHD 2014). The estuary provides a haven for aquatic species, serving as the last functioning estuary on the east side of the Kitsap Peninsula before leaving the waters of the Puget Sound.

Water Quality Data Collection

Water quality data was obtained from the Stillwaters Environmental Center in Kingston, Washington. Stillwaters sampled water quality monthly, at three sampling locations in Carpenter Creek, from 2001-2016 (Figure 6). Site 1 is located just north of the Carpenter Creek saltmarsh at (N 47°47'54.6966, W -122°30'48.6354) and is surrounded by mixed conifer stands of predominately, Douglas fir *(Pseudostuga menzessii*) and Western red cedar *(Thuja plicata).* Site 2 is located approximately 400 m north of Site 1 at (N 47°48.9958', W -122°30'45.4824) and is surrounded by similar mixed conifer stands, and is in close proximity of a small housing development. Site 3 is located upstream of Site 1 and Site 2 at (N 47°48'34.816, W -122°31'15.132) just north of Bond Road, the main highway into Kingston. Site 3 is also surrounded by mixed conifer stands. The sampling locations are all located within the City of Kingston's Urban Growth Area and have varying levels of urbanization.

Several water chemistry parameters were sampled at each sampling location. However, this study only used data from the following water quality parameters: temperature, pH, dissolved oxygen, discharge, nitrate, phosphate, and fecal coliform. These parameters were chosen based upon the ability to effect in-stream biota. All parameters, except fecal coliform, were recorded in the field by a team of trained volunteers utilizing established protocols. Grab water samples are taken for fecal coliform and sent to an accredited laboratory. Field data was recorded onto field datasheets and later transcribed into a digital format. For quality assurance purposes, the digital data was cross checked with field datasheets for inaccuracies.

Grab water samples were collection using WA State Department of Ecology Method EAP030 for Fecal Coliform and sent to Kitsap County Health Department for analysis. The grab water samples were taken in sterile bottles provided by the lab. Water samples were taken before field measurements to avoid contamination. After collection, the bottle is stored in a cool, dark cooler before transport to the lab. A second water sample, using the same protocols, was collected for field analysis of nitrate and phosphate. Phosphates and nitrates were measured using LaMotte water test kits, Phosphate Model VM12-Code 4408 and Nitrate Model NCR-Code 3110 (LaMotte, Chestertown, MD).

Digital multiparameter meters were used to obtain data for dissolved oxygen, pH and discharge (stream flow). Dissolved oxygen was measured using a YSI 200 Model Dissolved Oxygen meter (YSI Incorporated, Yellow Springs, OH). PH was measured using a multi-parameter meter, Hanna Model HI98129 (Hanna Instruments, Woonsocket, RI). Stream flow was measured using a current velocity meter, Swoffer Meter Model 2100-B (Swoffer Incorporated, Federal Way, WA). Digital readings from the meters were recorded on field datasheets.

Geographical Information Systems Data Collection

Geological and land use data for Carpenter Creek and the surrounding watershed were collected from local and national Geographical Information Systems (GIS) digital databases. Digital Elevation Maps (DEM) were obtained from the Kitsap County GIS database and downloaded into ArcGIS. Elevation data was extracted from the DEM raster datasets to create slope and elevation contour layers using ArcGIS Spatial Analyst. The mean, minimum, and maximum elevation and slope for each sampling location and the surrounding riparian area was calculated from this data. The slope and elevation did not differ vary significantly between sites.

Geologic data was obtained from the United States Geological Survey (USGS) GIS datasets. The USGS National Soils Database (NSD) GIS geodatabase was used to obtain soil classifications for the Foulweather Bluff/Appletree Cove watershed. The USGS National Hydrology Database (NHD) GIS geodatabase was used to obtain hydrological and wetland data for the study watershed. GIS data layers for the watershed were created from the geodatabases.

Land use data was obtained from the Coastal Change Analysis Program (C-CAP) regional land cover database and Kitsap County’s Comprehensive Plan landcover data. C-CAP is a nationally standardized database of 25 land use classifications at different time intervals, at 30-m resolution. C-CAP datasets from 2001 and 2006 were obtained for use in this study. These datasets were compared to Kitsap County’s Comprehensive Plan dataset to account for the most recent land uses located within the watershed. Land use classifications from both datasets were simplified and grouped into four categories: forested, urban, residential, and wetland. Although Kingston has served as a place of agriculture in the past, the existing land uses no longer reflect an agricultural classification.

To depict the most accurate data on the extent of urbanization within the watershed, road and Census data were obtained from the Kitsap County GIS data website. Road line layers were used to calculate road density within drainage basin and the stream buffer area. The number of single family taxlots (SFT) were obtained from Census TRACT 2010 data from the Washington State Geospatial Portal. Single family taxlots were used to measure the extent of imperviousness within the stream buffer area. The year-built dates for the SFT were used to calculate the amount of urban growth within the stream since 2001 (the beginning of the water sampling data). The C-CAP dataset was also used to examine the amount of imperviousness throughout the watershed and riparian habitat.

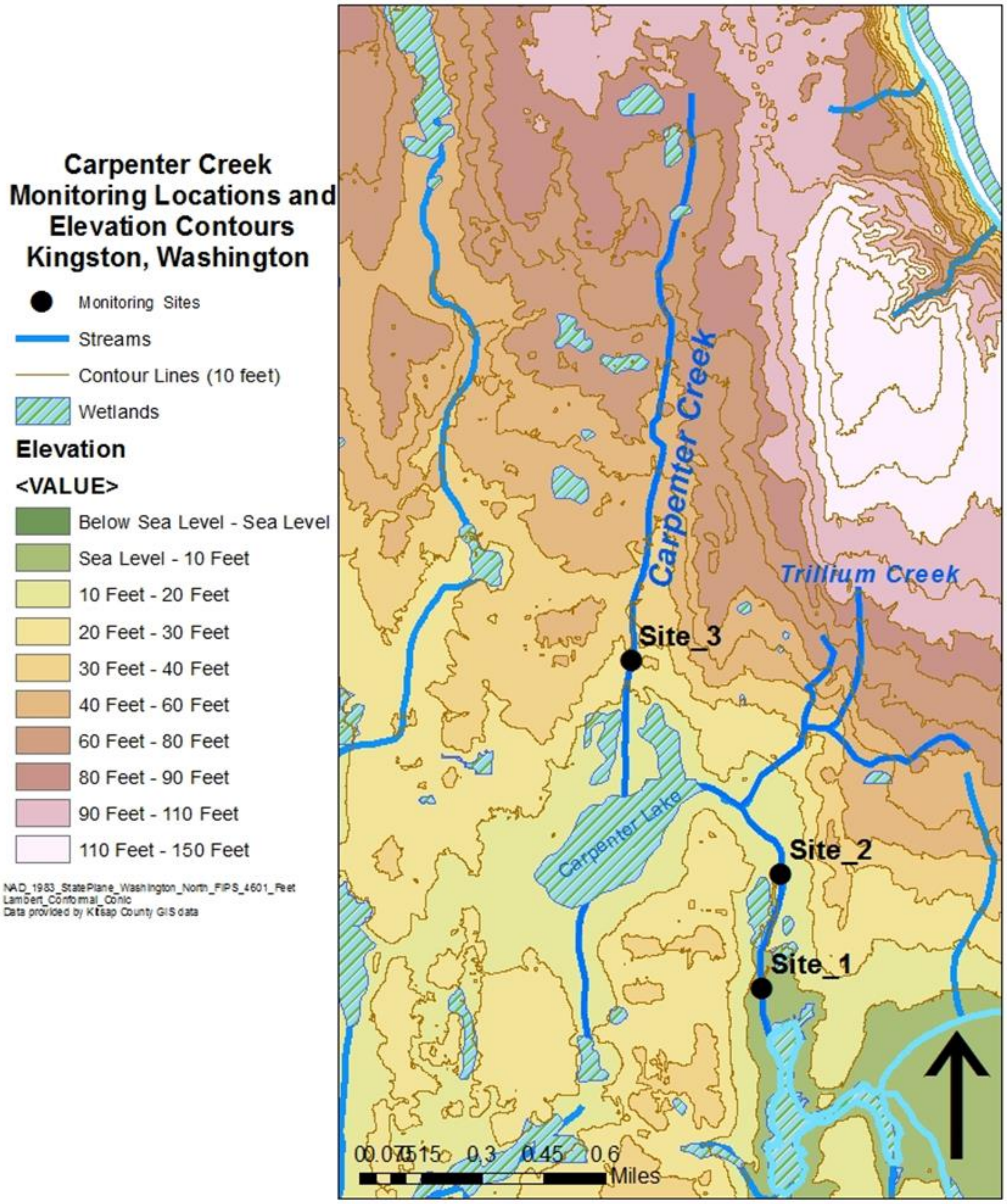


Figure 7 Elevation map of Carpenter Creek monitoring locations and surrounding areas.

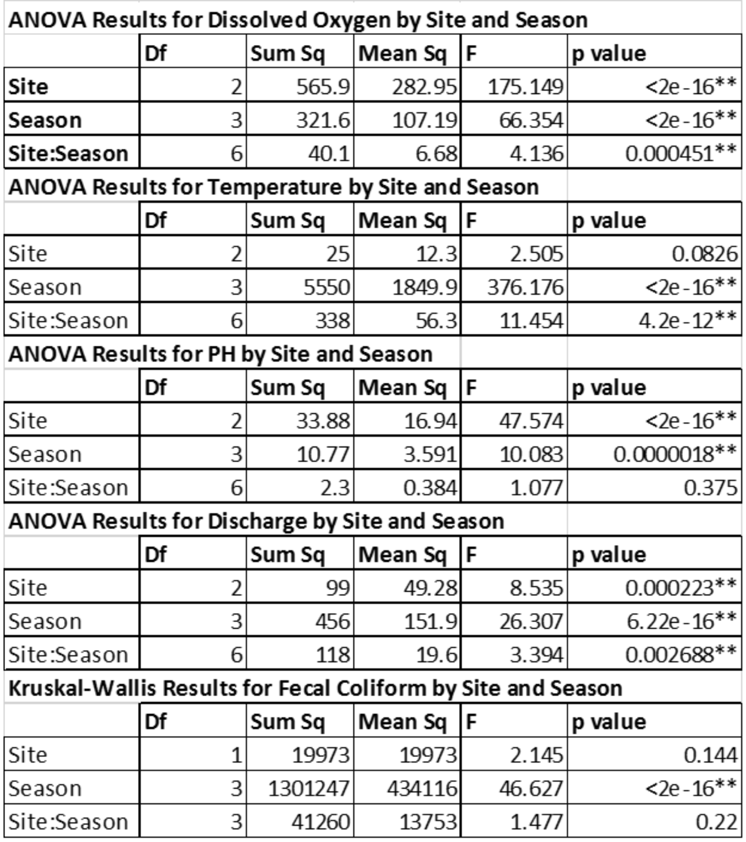
Results

Statistical Analysis

The water chemistry data was analyzed for missing data and outliers; extreme outliers were omitted from the data analysis. The water quality datasets provided by the Stillwaters Environmental Center were mostly complete with very few missing data points, missing data points were replaced with season parameter means. Most of the missing data were due to equipment malfunction or the inability to access the sampling site. A fourth sampling location was omitted from this study due to a difference in the length of sampling time. Monitoring did not start at the fourth site until 2004, while monitoring at the first three sites started in 2001. Several of the water chemistry parameters did not follow a normal distribution and were logged transformed before data analysis.

All statistical analyses were performed using R 3.1 software. A One-Way Analysis of Variance (ANOVA) or Kruskal-Wallis test were used to look for differences in water chemistry parameter means between Site, Season, Site and Season, and Percent Land Use Type. Tukey's Post-Hoc was performed to determine where the differences occurred. Significant differences were found in mean dissolved oxygen between Site and Season ($F_{(6,537)} = 4.14$, $p<0.05$). Differences in dissolved oxygen means were found between every site during every season ($p<0.05$). Significant differences were found in mean stream temperature between Site and Season ($F_{(6,338)} = 11.45$, $p<0.05$). Differences in temperature means between each sampling site were found during the Fall and Spring seasons ($p<0.05$), there was no difference in temperature between site during Summer and Winter seasons. Significant differences were also found in mean pH between Season $F_{(2,537)} = 10.08$, $p<0.05$and Site ($F_{(6,537)} = 47.57$, $p<0.05$). Significant differences in pH were found between Sites 2 and Site 3 during all seasons ($p<0.05$), and differences between Site 1 and Site 3 during the winter season ($p<0.05$). There are significant differences in discharge means between Site and Season ($F_{(6,537)} = 3.39$, $p<0.05$). Differences in discharge means were found between all Sites during the winter season ($p<0.05$). Significant differences were found in fecal coliform means between all sites during the summer Season ($F_{(6,537)} = 2.15$, $p<0.05$). The summer season fecal coliform means were all above the Washington State maximum for salmon-bearing streams (Figure 8).

*Table 1 Table of ANOVA and Kruskal-Wallis results for dissolved oxygen, temperature, pH, discharge, and fecal coliform by Site and Season. Statistically significant results are denoted with **. There are significant differences between dissolved oxygen by site and season (*$F_{(2,3,6)} = 4.136$, $p=0.000451$*), temperature by site and season (*$F_{(2,3,6)} = 11.454$, $p<0.05$*), pH by site (*$F_{(2)} = 2.505$, $p<0.05$*), pH by season (*$F_{(3)} = 10.083$, $p<0.05$*) discharge by site and season (*$F_{(2,3,6)} = 3.394$, $p<0.05$*), and fecal coliform by season (*$F_{(3)} = 46.627$, $p<0.05$*).*



ANOVA Results for Dissolved Oxygen by Site and Season

	Df	Sum Sq	Mean Sq	F	p value
Site	2	565.9	282.95	175.149	<2e-16**
Season	3	321.6	107.19	66.354	<2e-16**
Site:Season	6	40.1	6.68	4.136	0.000451**

ANOVA Results for Temperature by Site and Season

	Df	Sum Sq	Mean Sq	F	p value
Site	2	25	12.3	2.505	0.0826
Season	3	5550	1849.9	376.176	<2e-16**
Site:Season	6	338	56.3	11.454	4.2e-12**

ANOVA Results for PH by Site and Season

	Df	Sum Sq	Mean Sq	F	p value
Site	2	33.88	16.94	47.574	<2e-16**
Season	3	10.77	3.591	10.083	0.0000018**
Site:Season	6	2.3	0.384	1.077	0.375

ANOVA Results for Discharge by Site and Season

	Df	Sum Sq	Mean Sq	F	p value
Site	2	99	49.28	8.535	0.000223**
Season	3	456	151.9	26.307	6.22e-16**
Site:Season	6	118	19.6	3.394	0.002688**

Kruskal-Wallis Results for Fecal Coliform by Site and Season

	Df	Sum Sq	Mean Sq	F	p value
Site	1	19973	19973	2.145	0.144
Season	3	1301247	434116	46.627	<2e-16**
Site:Season	3	41260	13753	1.477	0.22

*Table 2 Table of parameter means and standard error for each monitoring site by season. Parameters measured are dissolved oxygen (mg/L), temperature (C), pH, nitrate (ppm), phosphate (ppm), discharge (cfs), and fecal coliform (colonies/100mL), respectively. A Tukey's Post Hoc test was performed and statistically significant differences are donated by *. There are significant differences in dissolved oxygen, temperature, and fecal coliform means between all sites and seasons. There are significant differences in pH between all sites during winter months, and pH means are significantly different at Site 2 during all seasons. There are significant differences in discharge means between Site 1 and Site 3 during the winter season. There are no significant differences in nitrate and phosphate means between site and season.*

Site	**Season**	**DO mn**	**±std**	**Temp**	**±std**	**pH mn**	**±std**	**NO_3 mn**	**±std**	**PO_4^{3-} mn**	**±std**	**Discharge**	**±std**	**FC mean**	**±std**
1	Fall	9.06*	0.14	9.74*	0.42	7.1	0.1	0.32	0.07	1.17	0.12	1.31	0.40	na	16.65
1	Spring	10.04*	0.14	9.99*	0.37	7.2	0.1	0.27	0.04	1.00	0.04	2.31	0.31	48.8*	12.69
1	Summer	8.73*	0.10	13.91*	0.23	7.2	0.1	0.34	0.06	0.99	0.04	0.59	0.08	141.04*	19.24
1	Winter	1.68*	0.17	4.91*	0.22	6.8*	0.1	0.37	0.07	1.10	0.12	3.8*	0.54	na	4.41
2	Fall	7.59*	0.14	8.11*	0.42	6.9*	0.1	0.31	0.05	1.00	0.02	1.04	0.35	na	49.67
2	Spring	8.9*	0.20	11.77*	0.34	6.9*	0.2	0.27	0.02	0.99	0.05	2.64	0.43	na	22.86
2	Summer	7.82*	0.16	14.65*	0.21	7.0*	0.1	0.31	0.03	1.14	0.06	na	0.12	267.18*	49.14
2	Winter	9.0*	0.23	NA	0.25	6.5*	0.1	0.46	0.16	1.14	0.13	na	0.64	na	6.24
3	Fall	10.36*	0.14	10.85*	0.38	7.5	0.1	0.34	0.05	1.00	0.01	0.79	0.21	144.4*	47.03
3	Spring	10.85*	0.20	9.47*	0.31	7.6	0.1	0.33	0.03	1.00	0.02	1.68	0.38	70.29*	21.95
3	Summer	9.63*	0.14	14.25*	0.21	7.5	0.1	0.85	0.51	1.05	0.03	0.55	0.09	267.19*	49.14
3	Winter	12.42*	0.28	5.53*	0.26	7.4*	0.1	0.38	0.06	0.95	0.03	1.17*	0.17	22.45*	5.97

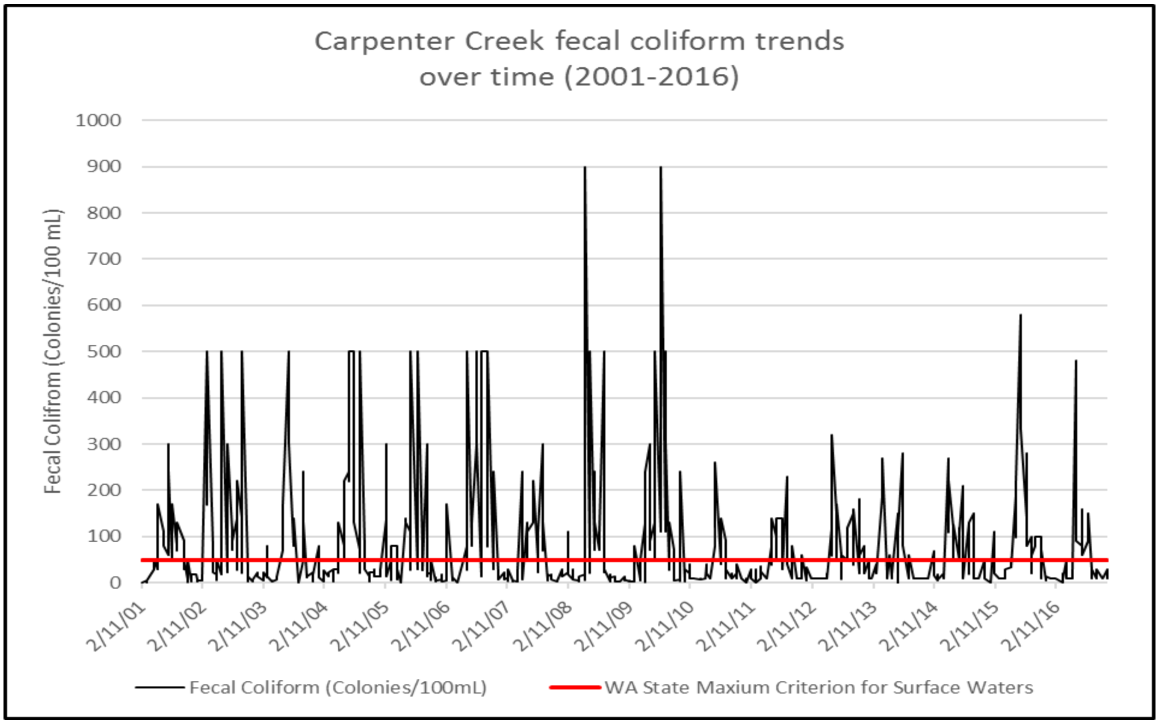


Figure 8 Line graph illustrating fecal coliform trends in Carpenter Creek from 2001-2016. Several measurements exceed Washington State maximum criterion for fecal coliform (50 colonies/100 mL).

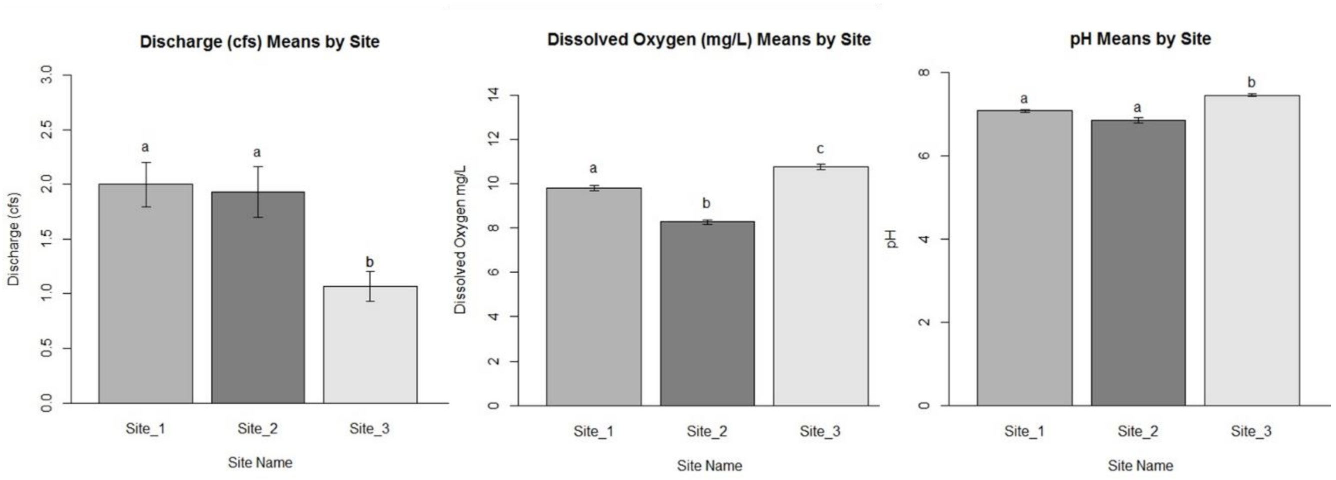


Figure 9 Bar graphs illustrating total discharge (cfs), dissolved oxygen (mg/L),and pH means and standard deviations by site. An ANOVA was used to determine if there were significant differences in parameter means between site. A Tukeys Post Hoc test was used to look where the differences occurred, statistically significant differences are denoted by differences in lettering.

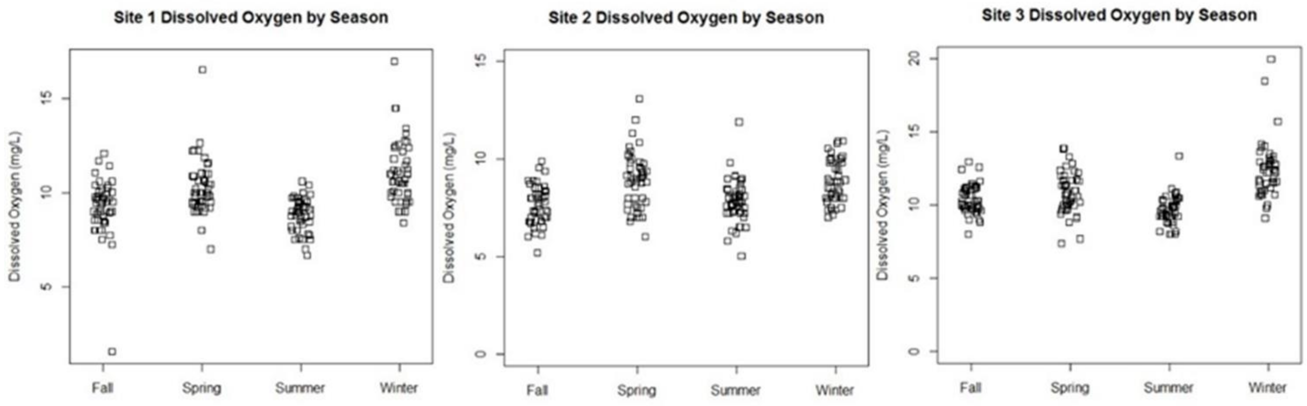


Figure 10 Scatter plot of Dissolved oxygen (mg/L) by Site and Season.

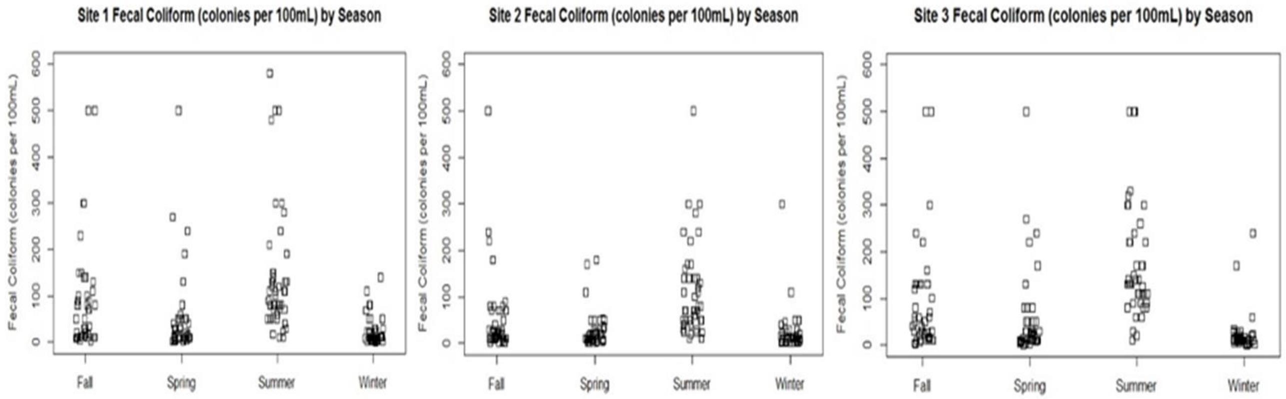


Figure 11 Scatter plot of fecal coliform (colonies/100mL) by Site and Season. There is a significant increase in fecal coliforms during the summer months at all sites.

Spatial Analysis

ArcGIS (ESRI 2015) was used to determine land use composition, percent land use and surface geology characteristics of the study creek and surrounding watershed. Elevation and slope were extracted from 30-m resolution DEMs provided by Kitsap County GIS databases. Geologic and hydrological data were obtained from the USGS GIS databases. Shapefiles and raster files were projected on NAD 1983 StatePlane Washington State North FIPS geographic coordinate system with a Lambert Conformal Conic projection. Land use shapefiles were provided by Kitsap County and the C-CAP project, these data were used to categorize land use types within the watershed and buffered stream section.

Using ArcGIS geoprocessing tools, a 200-m buffer was created around Carpenter Creek and its tributary. The buffer was created to understand the cumulative effects of riparian land use on water chemistry parameters within a stream reach. For each water sampling location, stream sections were delineated from the buffer, extending from the sampling location upstream to the headwaters. Each stream section represents the cumulative drainage area of the corresponding upstream sections. The average slope of each sampling site was found to be about 3.1%. While the sites differed in elevation, the difference was insignificant, with all site elevations between 10-40 feet above sea level.

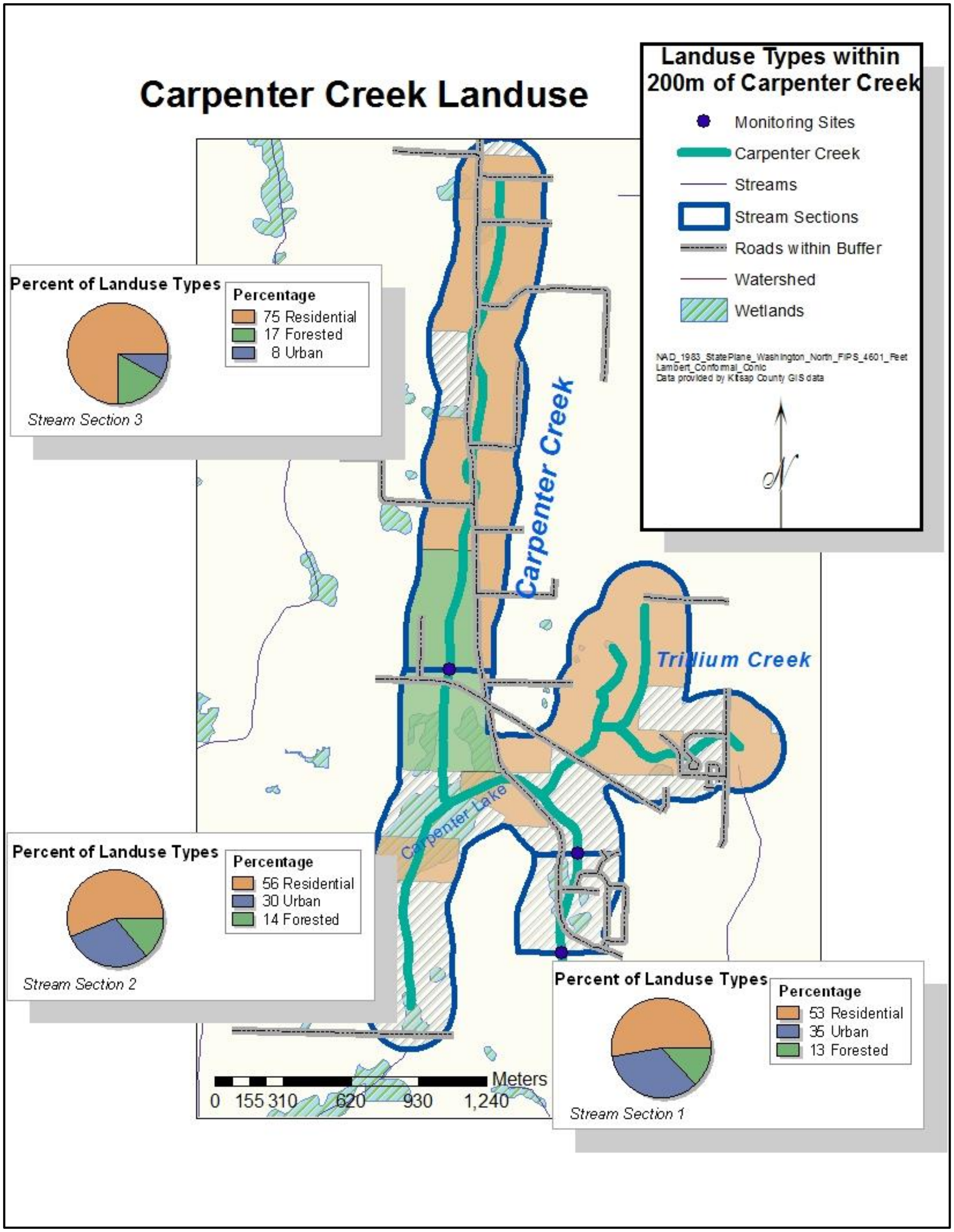


Figure 12 Map of land use types within a 200-m buffer of Carpenter creek. Stream sections are denoted by outlines.

Land use composition layer files were clipped to stream section layer files to calculate the percent composition of land use within each stream section. Land use shapefiles were compared with SFTs to account for residential land use on a small scale, and were found to align with SFTs with no adjustments needed. There were no significant differences between land use composition percentage between sites. Each site was found to have less than 20% forested land, with the majority land use urban or residential. SFT shapefiles were used to calculate the percent of residential and urban land use growth during the sampling period. It was found that urbanization has increased by 11% within the 200-m buffer of the stream during the sampling period. Road shapefiles were used to create road density maps, with road densities high within 200-m of all sampling sites. C-CAP 2001 and 2006 impervious data was used to create maps illustrating the growth of imperviousness within the watershed. Impervious surface raster data was only available for years 2001 and 2006, therefore impervious surface percentages were calculated using land use cover datasets.

Table 3 Geographical Information Systems data sources, data files, and landscape metrics used in analysis

Source	Data	Landscape Metrics
Kitsap County	Transportation Data	Street Density
Kitsap County	Population	Population Density (count/m2), Single Family Taxlots (SFT)
USGS	National Soils Database	Surface Geology Soil Types, % permability, % impermability
USGS	National Hydrology Database	Total Stream Length (m), Stream Density (km/m2)
C-CAP	C-CAP 2001, C-CAP 2006	% Imperviousness, % Forested, % Urban, % Residental, % Wetland
Kitsap County	DEM	Elevation, Mean Elevation, Min Elevation, Max Elevation, Mean Slope, Min Slope, Max Slope, % Slope
Ecology	Comprehensive Land Use Plan	Forested, Urban, Residental, Wetland

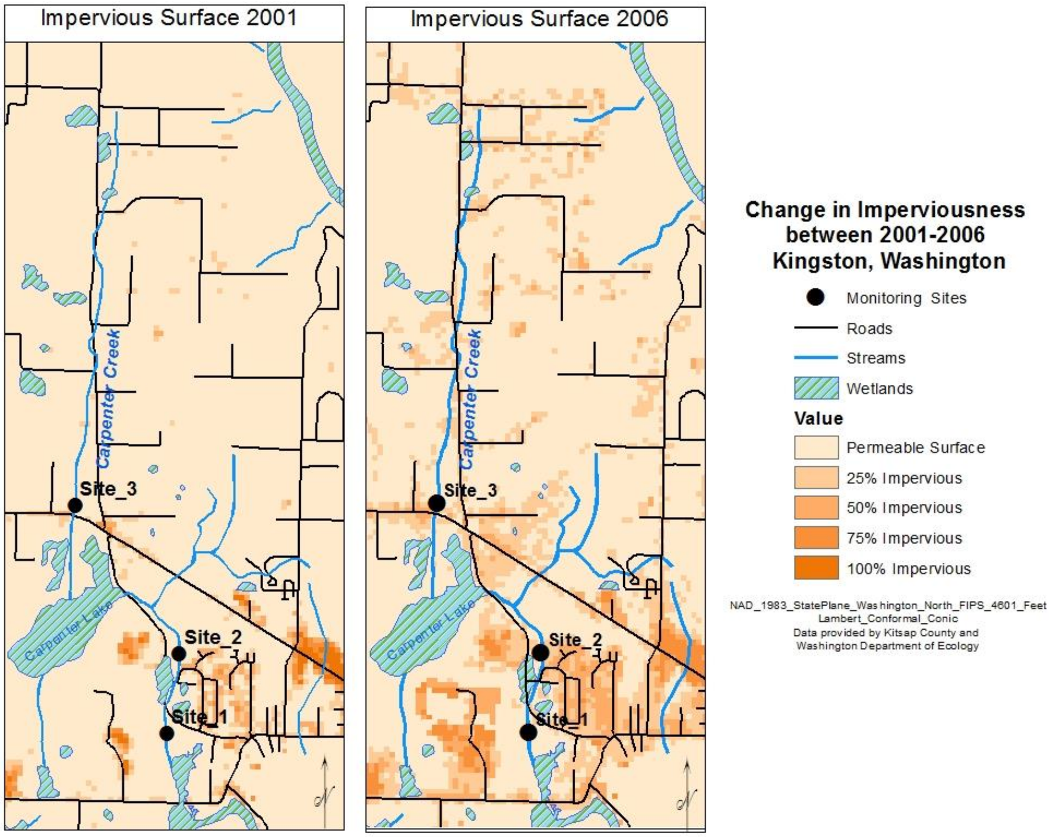


Figure 13 Map of percent of imperviousness within the Carpenter Creek basin for the years 2001 and 2006. The amount of imperviousness has increased rapidly within the five-year period.

Discussion

Statistical analyses showed significant differences in several water chemistry parameters between site and season for the 15 years of available data. Seasonal variation in water chemistry parameters is largely attributed to seasonal variation in precipitation events and human land use activities. Differences in parameters between site could be influenced by the physical characteristics of each site or a variety of geochemical properties that may be site specific, such as groundwater infiltration.

Dissolved oxygen (DO) was the most affected parameter, with significant differences in DO between every site and every season. DO is directly related to temperature through water solubility, therefore it is expected that differences in DO are directly related to differences in temperature. Temperature was found to be significantly different between all sites during the fall and spring seasons. The differences in DO and temperature means between season can be directly related to seasonal variation and precipitation influence. Significant differences were found in discharge and fecal coliform between all sites during the winter and summer months, respectively. The differences in discharge during the winter months can related to the different site geography and the associated flow at each location. It is hypothesized, that the high concentrations of fecal coliform at all sites during the summer season are related to land use practices including the use of fertilizers, and lower flows. These results are novel, and should encourage increased examination of the seasonal variation of urbanized Puget Sound lowland streams.

The percentage of land use did not differ significantly between site and therefore made model analysis unreliable. Multiple regression models did not show any relationships between land use category percentage and water chemistry measurements within the study scale. in the scope of the study examined land use-water quality relationships at the riparian buffer scale, and therefore the scale was restricted to a 200-m buffer around Carpenter Creek and its tributaries. Because this study was restricted in scope, the relationships between land use and water chemistry in lowland streams may not have been fully explained. The relatively small size of Carpenter Creek and relatively uniform geological and land use characterization of the surrounding riparian areas, limit the ability of statistical and spatial analysis to establish relationships between land use and water chemistry variables. Although the data obtained this study may not be sufficient in understanding land use and water chemistry relationships in Puget Sound lowland streams, it still provides valuable information about the characteristics of water parameters in these streams.

The data gathered and analyzed in this case study helps build upon existing literature on the water chemistry of small, urban, Puget Sound lowland streams. Although direct relationships between land use variables and water quality were not established in this research, trends in water quality chemistry between seasons in small urban lowland streams were identified. The trends identified in this study can be used to providing researchers with background information on urban lowland streams in Puget Sound. This research compliments existing literature (McCarthy et al. 2008, May 2009, Maloney and Weller 2011) which illustrates that urbanization influences the flow and movement of pollutions through a water system.

Although direct relationships between urbanization and other land uses were not established, the long history of fecal coliform contamination throughout the stream, displays a potential relationship between urbanization and increasing fecal coliforms. Interestingly, studies investigating fecal coliform concentrations in runoff in western Washington found high concentration loads associated with periods of high precipitation (Herrera Consultants 2007), whereas the data in this study show the highest fecal contaminations occur within Carpenter Creek during the summer season, where precipitation is at its lowest. This contradicts the current literature, and suggests that the high fecal coliform concentrations in Carpenter Creek are highly influenced by some mechanism other than precipitation. However, the factors affecting bacterial concentrations in roadway runoff in Western Washington have not been fully investigated (Herrera Consultants 2007). A study conducted by Kelsey et al. (2004) found that high concentrations of fecal coliforms were often found near septic systems. This study did not consider the location of septic systems. Given current literature, the high concentrations of fecal coliform during the summer season are probably directly related to human activity and this research could help provide insight on how to mitigate this water pollution.

The main limitation of this study, was the inability to complete some spatial analysis due to a lack of variation in geographical, geological, and land use data. The lack of significant differences between percent land use, soil type, precipitation, and elevation between sampling locations, made it difficult to run statistical models. The selected sampling sites were too physically similar to properly assess variation between site and make significant inferences about land use influence on the water chemistry. To mitigate this problem in future studies, researchers should use more sampling locations with different land use percentages and compare them. Perhaps, more sampling points along the stream would increase the variation between sampling location and may increase statistical and spatial analyses. In addition, urbanization grew 11% within the stream buffer system during the sampling period, this rapid urbanization of riparian areas could heighten the difficultly in assessing relationships between water chemistry and land use patterns.

Although this study may have limitations to describing land use and water quality relationships, the findings of this study help provide a significant amount of background information on urbanized Puget Sound lowland streams. This study also helps highlight the need for more research on bacteria pollution pathways in the Puget Sound and groundwater pollution pathways. Future studies should be conducted on land use variables and Puget Sound lowland stream water chemistry. It is possible that several of the water chemistry parameters are affected by groundwater processes and may not be recognizable through surface water measurements.

Conclusion

As urbanization continues to grow within our watersheds, it may become more and more difficult to analyze the relationships between land use and water chemistry. Although this study did not reveal a land use relationships to water quality, over 70% of the study sites are classified as 'residential' or 'urbanized' land use. Therefore, some trends in water quality may be related to land use, but they remained unnoticed due to homogeneity among sample sites. Past studies have emphasized the difficulty in analyzing land use relationships due to complex hydrological processes and the influence of past land use practices (Maloney and Weeler 2011). Continued anthropogenic alteration of the landscape, makes it extremely difficult to assess how different land use changes are influencing water quality. Stream systems, large and small, are influenced by several variables and are constantly in motion. Therefore, it may be difficult to study any true relationships existing between land use and water quality, unless the land use and activities around the stream stay static for the entire sampling period.

While land use and water chemistry relationships were not defined in this study, this research provides valuable information on water chemistry in highly urbanized Puget Sound lowland streams. This research found significant trends in fecal coliform concentrations and dissolved oxygen. Fecal coliform trends were significantly higher during summer seasons (dry season), which contradicts past research which found fecal coliform trends highest during high precipitation events. Trends seen in fecal coliform concentrations in Carpenter Creek exceed the state maximum for salmon bearing waters and imply a need for local planners to address this issue. This research implicates the need for further research into land use and water quality relationships in Puget Sound lowland streams, particularly groundwater fed streams of the Kitsap Peninsula, as well as a significant need to address the issue of bacterial pollution in Carpenter Creek.

Urbanization within watersheds has been found to have negative effects on the biological integrity of a stream system. Even though relationships between land use factors and specific water chemistry parameters remain largely unidentified, this research has identified water chemistry parameters that may be of interest for investigation in future studies. This study also investigated the seasonal water quality in Puget Sound lowland streams. In addition, the results of this research implicate that highly urbanized lowland streams may be especially susceptible to bacterial pollution. This may become especially important with climate change and the increased risk of pathogen transmission. Future studies should investigate these relationships further to establish a thorough understanding of these complex Puget Sound lowland streams.

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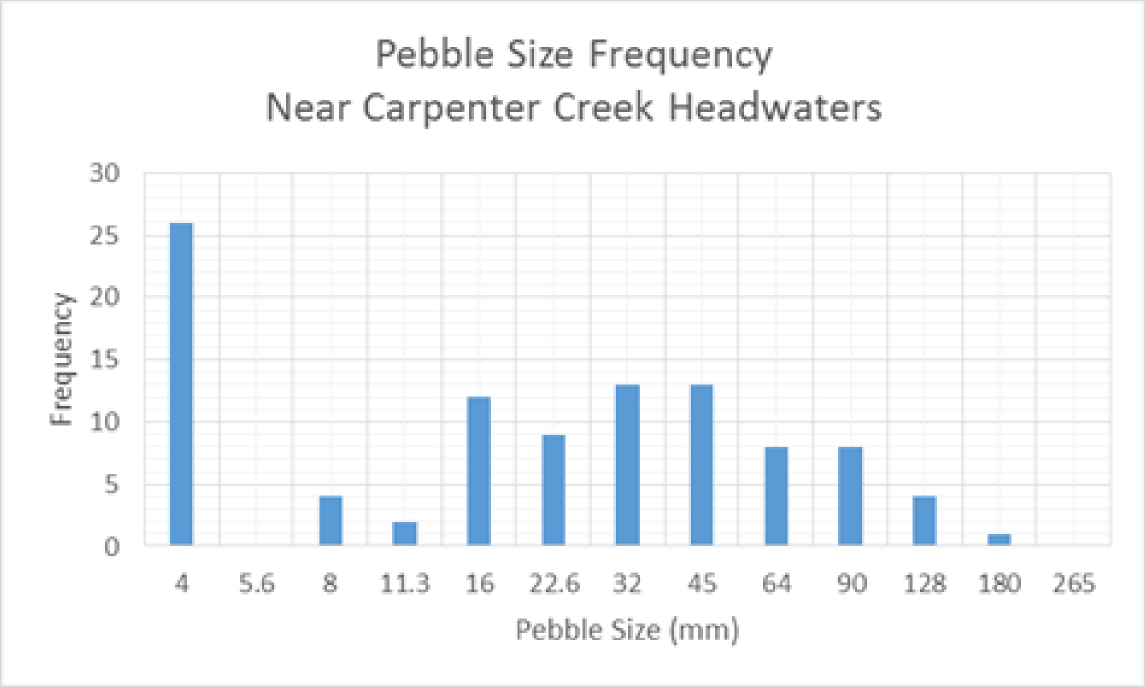
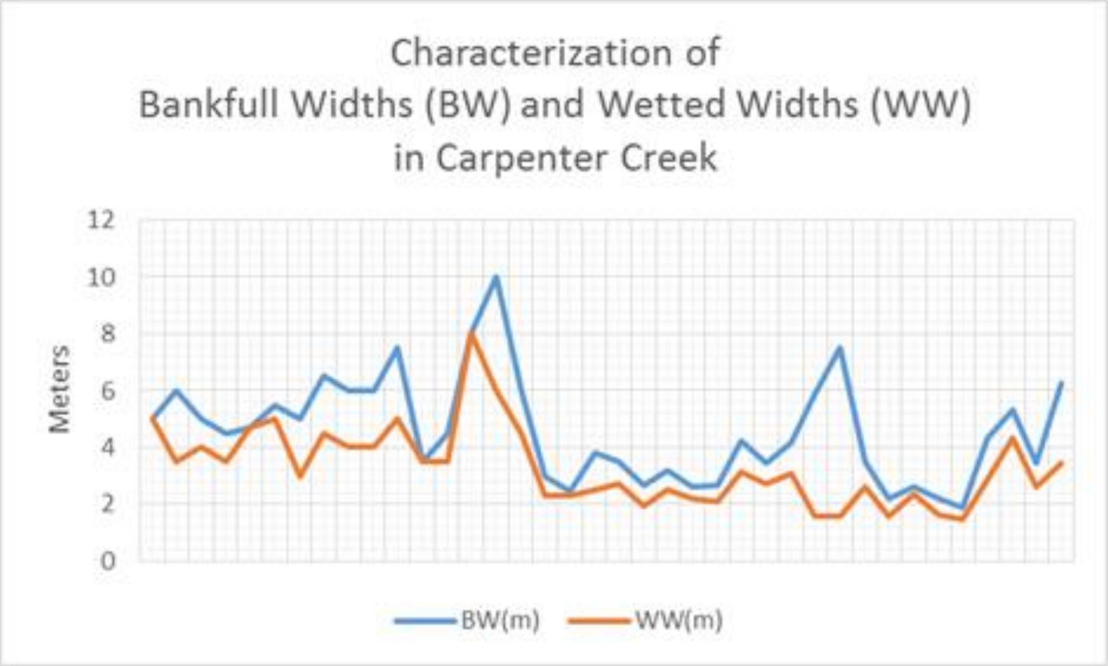
Appendices

Appendix 1. Pebble size frequency in a stream reach near the headwaters of Carpenter Creek in Kingston, WA.



Appendix 2. Characterization of bankfull and wetted widths from headwaters to the mouth of Carpenter Creek in Kingston, WA.



Appendix 3. Water chemistry data for Carpenter Creek (2001-2016). Data provided by Stillwaters Environmental Center.