An Evaluation of Land Cover Change from 2006 to 2009 and the Effectiveness of Certain Conservation Land Use Tools Within Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Riparian Buffers

Katrina Conlon Jensen

A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Urban Planning

University of Washington

2012

Committee:

Gordon A. Bradley

Donald H. Miller

Jan Whittington

Program Authorized to Offer Degree:

Department of Urban Design and Planning

University of Washington

Abstract

An Evaluation of Land Cover Change from 2006 to 2009 and
the Effectiveness of Certain Conservation Land Use Tools Within
Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Riparian Buffers

Katrina Conlon Jensen

Chair of the Supervisory Committee:
Dr. Gordon Bradley
School of Environmental and Forest Sciences

Riparian areas are fundamental to the ecological health for salmon recovery in the Pacific Northwest. Efforts to protect riparian areas for salmon recovery have typically focused on public land acquisitions and habitat restoration projects to meet near-term goals. This study evaluates the effectiveness of regulatory and voluntary conservation land use tools used for protecting riparian areas in the Lake Washington/Cedar/Sammamish watershed (Water Resource Inventory Area 8 [WRIA 8]) based on the presence or absence of land cover change. Aerial imagery from 2006 to 2009 and a vegetation change model developed by Kenneth Pierce with the Washington Department of Fish and Wildlife were used to characterize land cover change. In the last decade, new and more stringent land use regulatory tools and voluntary land use incentives have been established to help advance long-term strategies, such as conservation easements, transfer of development rights, Urban Growth Areas (UGA), and Critical Areas Ordinance (riparian buffers). The absence of land cover change in the riparian areas of parcels with conservation easements and TDRs are positive indicators that these conservation land use tools can be an effective alternative approach for advancing salmon recovery efforts. The presence of land cover change due to development and transportation projects associated with public and private lands inside the UGA was more than expected. Evaluating the effectiveness of riparian buffers administered by the local jurisdictions of WRIA 8 proved challenging, as jurisdictions and landowners are allowed to mitigate the riparian buffer width permitting variations. There is still much to learn on how jurisdictions are applying these new land use tools and how well they are working.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure Number Page

LIST OF TABLES

Table Number Page

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Professor Gordon Bradley, and my other committee members, Professor Donald Miller and Professor Jan Whittington, for their patience and support as I worked to finish my thesis. As busy as your schedules are, I appreciate you sticking with me.

A special thank you to Kit Paulsen. Kit, you are a wealth of thoughtful insights and I am so very lucky to have had the opportunity to work with you. Thank you for all your guidance and encouragement that has helped to shape my "rock".

Thank you to the WRIA 8 salmon recovery technical community with King County Department of Natural Resources and Parks. I am grateful for your time, data, and feedback from the early stages of my thesis development to the end.

Thank you to Kenneth Pierce with Washington Department of Fish & Wildlife. Without your model and results, this study would not have been possible. Thank you for the opportunity to participate in the WRIA 8 analysis. Good luck with future watersheds and incorporating 2011 data!

Thank you to Christopher Walter, with Forterra, for supplying me with the Cascade Land Conservancy's 2009 Protected Public Lands Database. The database was a critical component in my study.

To all my family and friends, thank you for all the moral support through this process. To my parents, thank you for being my #1 fan throughout life.

Above all, I would like to thank my love and best friend, my husband. Matthew, without your unconditional support and great patience, I may not have persisted.

DEDICATION

To my husband,

I am forever grateful for your support every step of the way.

INTRODUCTION

Riparian areas are fundamental to the ecological health and biodiversity in the Pacific Northwest. In Washington State's Puget Sound Region (PSR), protecting riparian areas is recognized as a key strategy for salmon recovery. Efforts to protect the riparian areas have typically focused on public land acquisitions and habitat restoration projects to meet near-term recovery goals (Shared Strategy 2005). This study will evaluate the effectiveness of regulatory and voluntary conservation land use tools used for protecting riparian areas. Land use tools will be evaluated based on land cover change results in the Lake Washington/Cedar/Sammamish watershed (Water Resource Inventory Area 8 [WRIA 8]).

Background on Salmon Recovery in Puget Sound

The degradation of salmon and their ecosystem in the PSR begins with Euro-American settlement in the 1850s (NWIFC 2012). The PSR Native Americans had sustained their culture and the surrounding natural resources for thousands of years prior to settlement (Shared Strategy 2005). However, by the end of the 1800s, the area's population growth exploded with settlers arriving to exploit the region's vast timber stands, highly productive fisheries, fertile soils, and rich minerals deposits (Shared Strategy 2005). Since 1889, Washington has lost 50 percent of its riparian habitat, 70 percent of its estuarine wetland, and 90 percent of its old-growth forests (NWIFC 2011). What were once wetlands near the deltas are now urban and industrial port areas; in the lowlands now spans agricultural fields, sub-urban sprawl, and big box storage warehouses; and the foothills and mountains have been converted to production forests and outdoor recreation areas (NWIFC 2012). Overall, riparian degradation in the PSR has a long history due to the fact that much of the transportation was by boat.

Early on, the PSR became a center for trade and commerce with its protected harbors, proximity to timber for shipbuilding, and proximity to Alaska during the Gold Rush. The region's draw for opportunity has also generated from the aviation industry since World War II and technology industries (Shared Strategy 2005). Today the PSR is home to over two-thirds the state's population with approximately 4.4 million residents (NWIFC 2012) with another 1.4 million people projected to settle by 2020 (Shared Strategy 2005). With the projected population

growth, further pressures will be placed on the land and the PSR's ecosystem; more homes, roads, and pipes systems will be needed to support these people. With more people and urbanization, more impervious surfaces will be created causing more pollution generated from stormwater runoff. Also, more impervious surfaces will prevent rainfall infiltration into the soil and cause runoff to become flashier. Flood hazards will increase causing stream scour and bank erosion to increase, thus sediment and pollution loading in the streams will increase; all of which contaminate and harm aquatic life that support salmon (Shared Strategy 2005). These physical alterations and human activities have contributed to the degradation of the regions' salmon runs and stocks, which has resulted in the listing of the Puget Sound Chinook, the Hood Canal summer chum salmon run, and the Coastal-Puget Sound bull trout to be listed as threatened under the Endangered Species Act (ESA) (NWIFC 2011).

In response to the 1999 listing of the Puget Sound Chinook Salmon, voluntary salmon recovery planning efforts where initiated through the Shared Strategy for Puget Sound (Shared Strategy) prior to an ESA mandate. The "Shared Strategy" was a grassroots collaboration of 150 representatives from federal and state agencies, Puget Sound tribes, local governments, and other key non-government organizations that came together to "develop a plan for Puget Sound that meets the needs of fish and people" (Shared Strategy 2005). Under ESA requirements, the National Marine Fisheries Service (NMFS) was responsible for developing recovery plans for the salmon listings; however, they recognized the Shared Strategy concurrently underway and agreed to support their efforts. With the NMFS's support, a small number of scientists were appointed to the Puget Sound Technical Recovery Team (TRT) to provide guidance and review on the Shared Strategy's salmon recovery plan and priority actions. In 2007, NOAA Fisheries Service adopted a final ESA recovery plan for Puget Sound Chinook (NOAA [date unknown]).

The Shared Strategy was divided into salmon recovery planning groups, organized by Water Resource Inventory Area (WRIA). In 2001, local jurisdictions within WRIA 8 signed an interlocal agreement that established the structure for decision-making and a funding source for salmon recovery planning for the watershed (Lombard 2003; WRIA 8 SC 2005). Under the agreement, the WRIA 8 Steering Committee was formed. It is responsible for developing and implementing salmon recovery plans specific for the watershed.

In 2005, the WRIA 8 Steering Committee released the WRIA 8 Chinook Salmon Conservation Plan. The plan recommends three key conservation action strategies: (1) site-specific habitat and restoration projects; (2) public outreach opportunities; and (3) voluntary land use actions such as incentives, best management practices, and alternative regulatory approaches. The plan further states that protecting existing intact forest cover is an essential strategy for conserving salmon in WRIA. Where forest cover has been disturbed, it is equally vital to preserve and restore the vegetation in the riparian buffers of streamside areas to protect the stream ecosystem.

Concurrent with the Shared Strategy for Puget Sound efforts, Washington State Legislation passed the Salmon Recovery Planning Act and formally created the Governor's Salmon Recovery Office (GSRO) in 1998 (GSRO 2000). Following the creation of the GSRO, Washington State Legislation approved a Salmon Recovery Funding Board (SRFB) with the purpose of providing state and federal grants to protect and restore salmon habitat statewide. From 1999 to 2010, the SRFB has administered over $788 million of state, federal, and local funds; nearly $420 million of which has been awarded. A majority of the funding has gone to habitat restoration projects and acquisition projects to protect pristine salmon habitat (RCO 2010).

In early statewide salmon recovery, short-term conservation action strategies were primary focused on acquiring the best remaining riparian habitat in the watershed (Lombard 2003). The ecological value of this approach was not without long-term concerns and high costs. Lombard (2003) raised concerns with this strategies' long-term success and the benefits the riparian habitat can provide, as recovery is also dependent on the overall protection of the basin, not solely on the riparian area. However, this short-term strategy was directed at protecting the most sensitive areas that were under the greatest development pressures. Development pressures were seemingly greater for riparian areas within urban and surrounding areas than in headwater forest. Today, more restrictive critical area regulations for riparian areas have since been amended to the state's Growth Management Act (2004) and Shorelines Management Act (2003) (WA DCTED 2003). These regulations may help fill the void between short-term and long-term conservation strategies. However, these regulations are still relatively new. There is still much to learn on how jurisdictions are applying these measures and how they are working.

There is a need for information on the effectiveness of the conservation action strategies, particularly between land acquisitions, voluntary land use actions, and alternative regulatory approaches in order to determine whether a "hands off" strategy for local regulations will ultimately meet salmon recovery goals.

Study Objective

The overall objective of this study is to advance salmon recovery strategies used for protecting riparian areas. This study will evaluate the effectiveness of land acquisitions, voluntary land use actions, and alternative regulatory approaches used to protect riparian areas along priority salmon spawning stream reaches in WRIA 8 based on an examination of WRIA 8 land cover change results from 2006 to 2009.

For this study, I assisted Washington Department of Fish and Wildlife's Kenneth Pierce Jr., PhD, with running a land cover change analysis for WRIA 8 in 2011. The land cover change analysis uses a high-resolution remote sensing modeling approach developed by Dr. Pierce. The model was designed for detecting land cover change across large areas such as the state's WRIAs quickly and consistently (manuscript by Pierce emailed to me 2011 May 27, unpublished; unreferenced). The model for WRIA 8 used orthorectified photographs from 2006 and 2009. The land cover change analysis is discussed in more detail in the Methods section below.

This study will examine WRIA 8 land cover change results focusing on riparian areas of priority salmon stream reaches. Using these results, the analysis will examine: 1) the predominate causes of land cover change, 2) the amount of change inside and outside the Urban Growth Area (UGA), 3) amount of change inside local jurisdiction's regulatory riparian buffer both inside and outside the UGA, and 4) the number of parcels and land ownership type associated with land cover change inside and outside the UGA.

This study will be presented in the following outline: background on riparian areas functions, background on conservation land use tools analyzed in this study, methods used for determining land cover change in WRIA 8, results from the land cover change analysis, discussion of findings, and recommendations for future actions.

Riparian Area Functions

A stream's ecological health is a function of its riparian area (Morley 2000). The riparian area can provide several benefits in protecting stream ecology in human impacted areas (May 2003). Riparian areas can improve the chemical, physical, and biological condition of the stream system through sediment filtration, erosion control, pollutant removal, large woody debris (LWD) recruitment, water temperature protection, wildlife habitat, and microclimate control (Knutson and Naef 1997; May 2003).

The effectiveness of the riparian area and its functions are largely dependent on the width, slope, the quality and quantity of vegetation (i.e., native species and undisturbed), continuous extent, soil type, buffer design and management (Herrara Environmental Consultants 2005), the number of stormwater outfalls in the stream (Leavitt 1998), and extent of upland development (FISRWG 1998).

Studies by Knutson and Naef (1997) and May (2003) have evaluated the beneficial functions riparian areas provide and their width (further referred to as "buffer"). These studies are documented in the King County Best Available Science (2004). Table 1 is a consolidated list the functions riparian areas can provide and their recommend buffers.

At the minimum recommended buffer width, 98-feet (ft), the riparian area can provide critical ecosystem functions for water quality treatment including pollution removal, water temperature protection, sediment filtration, and erosion control (May 2003). Soil and vegetation can reduce pollution and sediment loading by allowing filtration through the soil and transpiration through root and plant uptake (Leavitt 1998; May 2003). Vegetation cover in the buffer can provide shade control, thus water temperature protection (Leavitt 1998). Vegetation cover can reduce erosion by stabilizing the stream banks (May 2003).

The riparian area also may help reduce fine sediment loading by dispersing stormwater runoff and reducing sediment transport into the stream. The buffer allows increased infiltration before stormwater runoff reaches the stream, thus helping to reduce the peak flow volume. These beneficial functions are not applicable when stormwater is conveyed through pipes or channel to outfalls in the channel, completely bypassing the buffers (Leavitt 1998).

Riparian areas can influence the geomorphology of the stream depending on the quality

and quantity of intact, continuous vegetation available. The abundance and distribution of large woody debris (LWD) can provide stream habitat complexity such as pool, riffles, and glides that are the most critical component to salmonid habitat in the Pacific Northwest (May 2003). LWD also provides hydraulic stability to the stream ecosystem and reduces flows during peak flow events (May 2003). Vegetation in the riparian area can provide habitat and travel corridors for wildlife (WA DOE 2001), while providing nutrient sources for aquatic life and light patterning for salmonid and macroinvertbrate concealment (King County 2004).

Table 1. Riparian Area Buffer Functions and Ranges of Buffer Widths (feet)

Function	Range of Effective Buffer Widths by Knutson and Naef (1997)	Range of Effective Buffer Widths by May (2003)
Pollutant Removal	13 to 600-ft [78-ft average]	13 to 860-ft [98-ft minimum recommended]
Water Temperature Protection	35 to151-ft [90-ft average]	36 to 141-ft [98-ft minimum recommended]
Sediment Filtration	26 to 300-ft [138-ft average]	26 to 600-ft [98-ft minimum recommended]
Erosion Control	100 to 125-ft [112-ft average]	26 to 600-ft [98-ft minimum recommended]
LWD Recruitment	100 to 200-ft [147-ft average]	33 to 328-ft [164-ft minimum recommended]
Wildlife Habitat	25 to 984-ft [287-ft average]	36 to 141-ft [328-ft minimum recommended]
Microclimate	200 to 525-ft [412-ft average]	148 to 656-ft [328-ft minimum recommended]

Tools for Protecting Riparian Areas

There are a multitude of conservation land use tools available for protecting riparian areas and the functions they provide. For this study, land use tools are limited to approaches used by jurisdictions in WRIA 8 and by data availability and accessibility. A look at the conservation land use tools for this study includes: regulatory riparian buffer widths, urban growth areas, fee simple acquisitions, conservation easements that include native growth protection easements/areas, and transfer of development rights.

Riparian Buffer Widths

Riparian areas are defined by the Washington Department of Ecology (Ecology) as the transition zones between land and water environments (WA DOE 2001). These zones include the land, soil, and vegetation adjacent to a stream, river, wetland, or lake. The buffer is intended to be a continuous designation along both edges of a stream (King County 2005).

Under Washington State's Growth Management Act (GMA) (RCW 36.70A.060), all cities and counties are required to adopt critical areas regulations. "Fish and wildlife habitat conservation areas" (FWHCAs) are one of five "critical areas" defined under the GMA. As defined in WAC 365-190-130, FWHCAs are land management tools for the cities and counties to use for maintaining fish and wildlife populations in suitable habitats within their native geographic distribution. Under WAC 365-190-130, FWHCAs are intended as a long-term approach to supporting viable populations and preventing the creation of isolated subpopulations.

Under the establishment of the GMA's critical areas and the FWHCAs, cities and counties set critical areas ordinances (CAO) with stream or riparian "buffer" areas using best available science. The buffer zones around riparian areas should be used to protect population species, their habitat, and separate incompatible land uses from the FWHAs (WAC 365-190-130).

There are varying approaches in which these riparian buffer zones or widths are established and applied, particularly within jurisdictions in WRIA 8. Overall, the buffer width is based on a stream typing classification system, which may be further reduced or increased if other stream modifications apply (MRSC 2010). Stream typing and classification allows some flexibility in the appropriate level of protection necessary to maintain specific functions and processes of a stream depending on its size and other criteria. For instance, intermittent streams without fish present require less restrictive buffer widths. Alternatively, streams containing salmonid fish require a larger, more restrictive buffer width to ensure stream health (Herrara Environmental Consultants 2005).

Washington State currently has two stream typing systems established: an interim typing system is in use until the permanent typing is adopted. The interim stream typing system established in WAC 222-12-031 contains five stream types:

- Type 1- Streams and their associated wetlands that are considered "shorelines of the state" under 90.58 RCW,
- Type 2- Other segments of natural waters than Type 1 with a high fish, wildlife, or human use,
- Type 3- Other segments of natural waters not classified as Type 1 or 2 Waters, and have a moderate to slight fish, wildlife, or human use,
- Type 4- Perennial, nonfish habitat streams, and
- Type 5- Seasonal, nonfish habitat streams.

The permanent stream typing system, established in WAC 222-16-030, consists of four stream types:

- Type S - Streams and their associated wetlands that are considered "shorelines of the state" under 90.58 RCW,
- Type F - Other natural waters than Type S with a 0.5 acre or greater of seasonal low water and contain fish habitat,
- Type Np - Perennial, nonfish habitat streams, and
- Type Ns - Seasonal, nonfish habitat streams.

The permanent stream typing is a design based on fish habitat locations generated from a multiparameter, field verified geographic information system (GIS) logistics regression model that inputs variables such as basin size, elevation, gradient, elevation, and more (WAC 222-16-030).

This study is particularly concerned with regulatory riparian buffer widths related to fish bearing streams (i.e., Class I, Class II, Type S, and Type F). A summary table of local jurisdictions' regulatory buffer widths is in Appendix A.

Implementing the Riparian Buffer Width

Jurisdictions in WRIA 8 have different approaches to implementing the riparian buffer width. The width can be applied using a fixed or variable width, Three- and Two-Zone buffer widths, buffer averaging, and buffer reduction/enhancement. Further variance for building structure setbacks may apply in order to prevent disturbance to riparian functions within the stream buffer (May 2003; Herrara Environmental Consultants 2005).

Fixed versus Variable Buffer Widths

A fixed buffer width is an established streamside area. This buffer approach is generally the result of political resolve and is often unsuccessful at protecting all the ecological functions of the riparian area (May and Horner 2000); however, a fixed buffer can be easily applied and requires less specialized personnel, time, and money to administer the regulation (Castelle et al. 1994). Alternatively, a variable width buffer offers more flexibility for landowners, developers, and the jurisdiction. Variable buffer widths can be specific to the conditions and ecological goals at an individual site. Because this approach evaluates site specific environmental and management goal, it is considered more ecologically sound (Haberstock et al. 2000; IMST 2002 cited in King County 2004).

Three- and Two-Zone Buffer Widths

The Three- and Two- Zone buffer widths are approaches that consider both the riparian functions and acceptable uses per each zone. In Zone 1 of the Three-Zone Buffer, the zone is adjacent to the stream and protects the critical functions of the stream ecosystem. Examples of activities allowed in Zone 1 include utility right-of-way, footpaths, and flood control (Herrara Environmental Consultants 2005). Zone 2 is intended to provide the buffer between development and Zone 1. Examples of allowed uses in Zone 2 include bike paths and outdoor recreation (Herrara Environmental Consultants 2005). Zone 3 is at the outer edge of the stream buffer zones. The intent for Zone 3 is to prevent encroachment and provide stormwater runoff filtration. Structures are not allowed in Zone 3; however, unrestricted residential uses such as lawn, gardening, and compost piling are acceptable (Stormwater Center 2004; as cited in Herrara Environmental Consultants 2005).

The Two-Zone buffer widths separate the stream buffer into two zones: the inner zone is a "no touch" zone and the outer is a "management zone". In the "no touch" zone, the area is recognized as providing a majority of the critical riparian functions to a stream, thus very limited disturbance is allowed in this area. More uses are allowed in the outer "management zone" as it provides relatively fewer benefits than the inner zone (May 2003).

Riparian Buffer Width Averaging

Riparian buffer width averaging offers another component of flexibility for applying a riparian buffer. The buffer width may be reduced if additional area is added elsewhere adjacent a

riparian area and other site criteria are approved. Examples of local restrictions for averaging buffer widths in WRIA 8 jurisdictions include:

- The total buffer area, after averaging, should be no less than the standard buffer, or the area required before averaging,
- The buffer is contiguous with the existing buffer (King County 2005),
- The buffer width should not be reduced more than a prescribed percentage (33 percent in Kirkland or up to 50 percent in Snohomish County) of the standard width at any single location. Snohomish County allows up to a minimum of 25 ft, whichever is greater (Snohomish County Code 30. 62.350), and
- The functions and value of the stream and buffer will not be negatively impacted (Edmonds Municipal Code 23.90.040.D).

Riparian Buffer Width Reduction/Enhancement

The riparian buffer width may be reduced through a buffer enhancement approach only if it can be demonstrated that the buffer enhancement will provide higher functional value than the performance of the existing buffer width. In the City of Kirkland, buffer enhancement includes removing invasive plant species, planting native vegetation, or installing stream and riparian habitat features such as large woody debris (Kirkland Municipal Code 90.100.1.b). Other restrictions or terms may apply similarly to buffer averaging. In general, the overall functional value of the stream protected may not be reduced.

Urban Growth Area

In 1992, local communities established Urban Growth Area (UGA) designations as directed under Washington State's GMA (RCW 36.70A.060). These UGAs are designated "areas and densities sufficient to accommodate the country's expected growth for the succeeding 20 years" (WA Dept. Community Dev. 1992). UGAs are a regulatory conservation land use tool for encouraging development and urban growth in areas already disturbed or better suited with facilities to support growth. In addition to designating growth areas, this land use tool is intended to encourage setting aside areas for rural uses and natural resource protection (WA Dept. Community Dev. 1992). Although this tool does not directly protect against encroachment in the riparian buffer, it is intended to prevent fragmented development within threatened, intact forest tracts.

Fee Simple Acquisition

A fee simple acquisition is a conservation land use tool best used when an area is highly sensitive or threatened, and the only means for sufficient protection is to purchase the land outright (Fishburn et al. 2009). In a fee simple acquisition the purchaser holds all rights to ownership and possession. The owner holds full control over future land development and conservation management strategies. This mechanism has a high potential to achieve long-term conservation goals (Greene et al. 2009).

In a fee simple acquisition the cost is a function of the land development potential, thus as development potential increases so does the capital cost of the property. Other costs may be associated such as the long-term maintenance and monitoring of the lands (Greene et al. 2009).

Fee simple acquisition is a mechanism used by the Salmon Recovery Council to protect forest cover and the riparian buffer. Fee simple acquisitions for public lands are categorized as "protected public lands" for the purpose of this study.

Conservation Easements

A conservation easement is a voluntary, legal contract between a landowner and government agency or conservation group that restricts a portion of the property's development rights associated with the land in such a way that advocates conservation (Dana and Ramsey 1989). Conservation easements can be used to target desired portions of a property (i.e., riparian buffer) more easily and at a reduced cost, than fee simple acquisitions (Greene et al. 2009).

The portion of the property under easement will continue to be owned and managed by the landowner. The property may be sold or passed on as normal. Conservations easements may further provide lower property taxes for the landowner if the market value for the land is lowered when the development right is removed (LTA 2008).

Native growth protection easements (NPGEs) and native growth protection areas (NGPAs) are two other forms of a conservation easement. For this study, NPGEs and NPGAs are consolidated with "conservation easements". NPGEs and NPGAs are two similar types of conservation land use tools for local jurisdictions to record a dedicated vegetation protection easement or tract directly on the deed of the property. The NPGE and NPGA give a record of the

critical areas and provide additional protection by preserving the native vegetation under the property's development rights (Walker 2012).

A NPGE is an easement recorded on the property, similar to a deed or notice on the title, and is applied to Short Subdivisions (RCW 58.17.060) or development actions on single parcels where critical areas protection is required (Walker 2012).

A NPGA is a tract or separate tax parcel, generally created by a Short or Long Plat Division (RCW 58.17), Planned Actions (RCW 36.70A.040 and WAC 197-11-164), or with land use critical areas permits (Walker 2012).

Transfer of Development Rights

Transfer of development rights (TDRs) allow landowners in "sending areas" to transfer their development rights and densities to landowners in "receiving areas" where higher density development is allowed (Freilich and Davis 1981). TDRs can be used to help direct development from areas that are environmentally sensitive, such as areas surrounding riparian buffers, to areas that are highly developed (Miller 1999).

METHODS

Study Area

This study area covers the Lake Washington/Cedar/Sammamish Watershed (WRIA 8) in the Puget Sound Region of Western Washington (shown in Figure 1). WRIA 8 covers 692 square miles (HWS [date unknown]), from the marine shores of the cities of Seattle and Everett extending southeast into the Central Cascade Mountains. WRIA 8 contains two major river systems (Cedar River and Sammamish River), several creeks, and three large lakes (Lake Washington, Lake Sammamish, and Lake Union) that drain through the Ship Canal and Hiram M Chittenden Locks (Locks) to Puget Sound. These lakes and rivers have been highly altered due to development and urbanization. Construction of the Locks in 1916 and the Ship Canal rerouted the outlet of Lake Washington from the Black River, which flowed into the Duwamish River and on into Elliott Bay, to Lake Union on through the Locks and into Puget Sound. The construction and reroute dropped Lake Washington water levels about nine feet, draining much of the lake's shorelines and effectively eliminating 1,300 acres of wetland habitat (Shared Strategy 2005). The Cedar River has been highly impacted since construction of the Landsburg Dam in 1901 for Seattle's drinking water, which blocked 17 miles of salmon spawning habitat. Further shoreline impacts occurred in the 1950s as levee systems were constructed for flood protection on the Cedar and Sammamish rivers and with railroad development. Railroads make up 87 percent of the watershed's marine shorelines (Shared Strategy 2005).

WRIA 8 is primarily located in King County, with 15 percent if its area in Snohomish County, and consists of 27 local governments (Shared Strategy 2005). The WRIA is home to the most densely populated watershed in the state (WRIA 8 SC 2005). Much of the population resides in the Seattle Metropolitan area (including King, Pierce, and Snohomish counties). In the last decade, the vast majority of the population's growth has occurred in the outer suburbs and exurban areas (Cox 2011). This means greater development pressures have been put on undeveloped, vegetated areas.

Tiers

This study examines land cover change within the riparian area of priority salmon spawning reaches identified by Leonetti et al. (2005) in the Technical Appendix C-2 of the WRIA 8 Chinook Conservation Plan (Figure 1). Leonetti et al. (2005) prioritized WRIA 8 tributary subbasins into three "Tiers" based on Chinook salmon use and the relative watershed condition. The Tiers are used as a planning tool to ensure conservation strategies are appropriate for each area. Tiers 1 and 2 are determined to be most important for overall Chinoook salmon recovery (Leonetti et al. 2005).

Leonetti et al. (2005) characterizes WRIA 8 subbasins by the following three conservation strategy Tiers:

- Tier 1: These subbasins contain core spawning and obligatory rearing and migratory areas for Chinook salmon in WRIA 8. Without these areas, the WRIA 8 Chinook salmon population could not complete their life cycle. Tier 1 subbasins are mostly in rural areas outside the UGA boundary and contain vast areas of intact forests (Vanderhoof et al. 2011).
- Tier 2: These subbasins contain less frequent spawning areas and are in moderate to high watershed condition. These areas are considered critical for maintaining and improving the spatial structure of the Chinook salmon population in WRIA 8, which are dependent on the spatial distribution of abundance. Subbasins in Tier 2 may provide productive areas for Chinook if abundance increases in the future and if high watershed conditions can be maintained. These subbasins are located within and outside the UGA boundary.
- Tier 3: These subbasins serve lower watershed functions. These subbasins have significantly impaired watershed processes and degraded aquatic habitat. The salmon production and abundance is naturally limited based on subbasin size, channel width, gradient, and length of suitable habitat. The subbasins in Tier 3 are primarily located inside the UGA boundary.

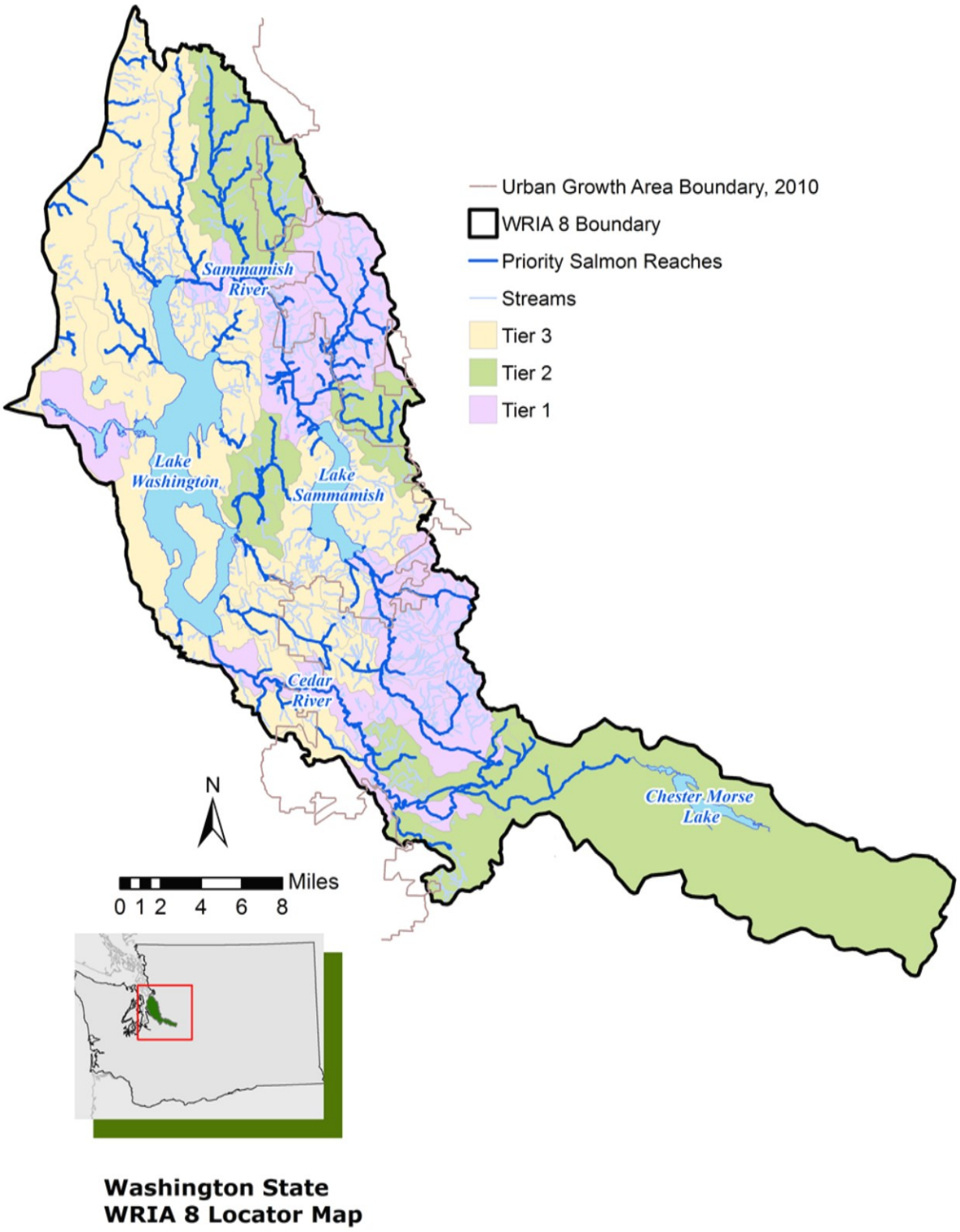

Figure 1. Lake Washington/Cedar/Sammamish Watershed (WRIA 8) map and Tiers 1, 2, and 3 Subbasin

High-Resolution Land Cover Change Detection with Remote Sensing

Kenneth Pierce developed a modeling approach for quickly and consistently mapping major land cover change at a large aerial extent using high-resolution remote sensing data (i.e., aerial imagery). This method uses National Agriculture Inventory Program (NAIP) aerial imagery collected during the agricultural growing season in the continental US (USDA FSA 2011). The NAIP imagery is based on one-meter pixel coverage size. This is higher resolution than typical land cover change models that have used LandStat data with 30-meter resolution. The higher resolution improves capabilities in recognizing features and identifying more precise areas (manuscript by Ken Pierce emailed to me May 27, 2011, unpublished; unreferenced).

As part of this study, I assisted Pierce with his analysis of land cover change in WRIA 8 that occurred from 2006 to 2009. The process for mapping high-resolution vegetation change in WRIA 8 is summarized in five main steps.

1. **Image Acquisition and preparation:** The 2006 NAIP data is a pixel size of 0.5-m resolution and three-color bands [Red, Green, and Blue (RGB)], while the 2009 data is available in 1.0-m resolution and four-color bands [RGB and Near Infrared (IR)]. Pierce resampled the 2006 data at a 1.0-m resolution and the RGB-color bands were extracted from the 2009 in order to compare the two data sets.

2. **Spectral based shadow and vegetation modeling:** The 2009 data histograms were then matched to the 2006 data. This step normalized pixel values depicting similar conditions between the two images and was then used for determining the spectral differences.

   The 2009 near-IR band and the green bands were used with the ERDAS software feature classification tool to classify vegetation density into three classes: non-vegetation, grass/field, and mature shrub/forest.

   Pierce created a shadow mask to minimize the shadow effect created from building structures, bridges, tree crowns, etc. from both data sets. Using shadow height as an indicator, the shadow mask can separate homogeneous green forest stands from homogeneous green agricultural fields.

3. **Image segmentation:** In a process called image segmentation, Pierce aggregated the 1.0-m pixels into statistically homogenous regions, representative of different landscape features or land-cover areas. These segments and their size were based on the spectral differences determined from the 2006 and 2009 red, green, blue color-band data, the shadow mask data, and the 2009 near-IR vegetation density classification data. This process created a segment, or polygon, based on the grouping of the pixels using Definiens (Trimble) eCognition software.

4. **Training and statistical modeling:** I assisted Pierce with training the predictive change model by classifying a sample of image polygons between 2006 and 2009 imagery. The sample was divided into two groups based on the amount of green band change. These sample groups were then used with the polygon attributes from previous steps to train the predictive model for nine classes including: reductive change, such as, major changes from forest cover to grass or other natural condition to impervious surfaces; agriculture landscape; shadows; urban landscape; forest cover; grass/shrub landscape; wetland; growth in vegetation; and mix, where there is a mix of vegetation, non-vegetation, and impervious surfaces in the segment.

   Pierce built the model using the Random Forest recursive-modeling algorithm, an extension of classification and regression trees (CART). Using Random Forests, thousands of CART models were generated from the sample of image polygons. Each CART model generated was a prediction of a polygon's class. The most frequently predicted class determined which class was assigned to the polygon. This is why the process is referred to as a "predictive" model ("predictive" is not used in common academic sense that it is predicting future change).

5. **Analyst review and accuracy assessment**: The predictive model sorted the results into two populations: polygons with predicted change and polygons without predicted change. All polygons predicted as change were reviewed because there were relatively less of these polygons identified. Further the predicted change polygons directly affect

the final product of the change model. In this step, polygons incorrectly predicted as change are removed, effectively eliminating any errors of commission in the model. Approximately three percent of the remaining no-change polygons were reviewed for any changes not detected by the model to remove any errors of omission (email correspondence with Ken Pierce on June 6, 2011; unreferenced).

WRIA 8 Land Cover Change Analysis Results

Results from the WRIA 8 change analysis[1] revealed 1,749 change segments, equaling 2,175 acres of total mapped change. These change segments were classed into three change codes: forestry/unknown (No.1), development (No.2), partial change (No.6). Of the change segments, 1,524 segments (1,952 acres) were classified as development, 126 segments (199 acres) as forestry/unknown, and 99 segments (24 acres) as partial change. If the total change in a segment appeared to be between 25-50 percent of the polygon, then we coded the segment as partial change (email correspondence with Ken Pierce on June 6, 2011; unreferenced).

The error of omission for WRIA 8 is 0.3 percent, or 19 acres out of a total 6,694 acres reviewed, which translates to an estimated 1,145 acres of the 403,000 acres in WRIA 8 not predicted as change in the model. Overall, the total amount of vegetation change in all of WRIA 8 is approximately 3,320 acres, a yearly change rate of 0.27 percent [2] (email correspondence with Ken Pierce on June 6, 2011; unreferenced).

Building a Geospatial Database to Review Land Use Tools

Using ESRI ArcGIS 10 mapping software, a geospatial database was developed from publicly available GIS data such as public and private parcel data, urban growth area boundaries, watershed boundaries, waterways, and roads accessible online through the Washington State Geospatial Data Archive website, Washington Department of Ecology GIS Data website, King County GIS Data Portal website, and Snohomish County Department of Information Services website. A summary list of GIS source data is provided in Appendix B.

---

[1] Kenneith Pierce has made the change segment results for WRIA 8 and other WRIAs available for download at: http://dl.dropbox.com/u/12789079/Distribution.zip.

[2] There is 2,175 acres of change predicted from the model, plus 1,145 acres of change estimated from the error of omission, equals the 3,320 acres of vegetation change. Dividing 3,320 acres by 403,000 acres (area of WRIA 8) equals 0.008, then divide by three years and multiply by 100, equals a 0.27 percent rate of vegetation change per year.

Additional GIS data was provided by request:

- Forterra[3], formerly The Cascade Land Conservancy, generously provided their 2009 Central Puget Sound Protected Lands Database (CPS-PLDB)[4], a geospatial database of protected lands and conservation easements (email correspondence April 26, 2011; unreferenced),
- The Salmon Habitat Work Schedule group provided data on land acquisitions and salmon habitat restoration project work within WRIA 8 (email correspondence April 18, 2011; unreferenced), and
- King County Water and Land Resources Division Department of Natural Resources and Parks provided geospatial data specific to WRIA 8 priority salmon stream reaches (email correspondence; unreferenced).
- King County Department of Natural Resource Protection (DNRP) provided TDR GIS data (email correspondence April 8, 2011; unreferenced).

Determining Land Cover Change in the Riparian Buffer

Three buffer widths (50-ft, 100-ft, and 165-ft) were generated in ArcGIS 10 around the priority salmon stream reaches that were provided by Vanderhoof et al. (2011). The buffer widths were chosen to account for the various ranges of jurisdiction regulatory buffer widths applicable in WRIA 8. Within the jurisdiction of Montlake Terrace, the buffer width search was expanded to account for their maximum regulatory buffer width applicable, up to 240-ft for Class I streams (Montlake Terrace Municipal Code 16.15.090). A table summarizing local jurisdictions' regulatory stream buffer widths is provided in Appendix A.

Land cover change segments that intersected with the buffer widths of the priority salmon stream reaches were selected from the WRIA 8 land cover analysis results. The selected change segments intersecting the regulatory buffers were individually examined to determine the observed cause of the change between 2006 and 2009, the associated parcels, the parcel's land ownership type (public or private), applicable conservation land use tools, applicable regulatory buffer, Tier number, and the location inside or outside the UGA boundary. These change

[3] The Cascade Land Conservancy changed its name to Forterra in November 2011.
[4] CPS-PLDB (2009) was acquired April 26, 2011, before the name changed from Cascade Land Conservancy. This document is unpublished and unreferenced.

segments were further classified into five categories by the observed cause of change to be more informative. The land cover change classes are: natural events, development, transportation project, reduced vegetation by human disturbance, and public works project.

Polygon segments that were within its local jurisdiction's riparian buffer were selected out for this study. In order to quickly assess the amount of land cover change of these segments, the segments were clipped using ArcGIS to the 165-ft buffer and then summed.

For this study, natural events are defined as land cover changes related to stream channel migration (i.e., the stream channel naturally shifts in its floodplain). It is assumed these natural events are occurred by intense storm/rainfall events. Development is defined as vegetation cleared to bare soil and/or building structures developed on the site. Transportation projects are defined as any change related to road construction, road expansion, or bridgework activities. Reduced vegetation by human disturbance is defined as any vegetation reduced, but vegetation still remains (i.e., trees were cleared, but pasture land remains). Public works project is defined as land cover change resulting from a Snohomish Wastewater Treatment facility in Lynwood, WA spanning multiple parcels.

Land ownership types were categorized into five types: private, public right-of-way (ROW), water body in the plat ("HYDR"), protected public lands, conservation easements, and TDRs. Land ownership types were derived from the information available within existing parcel databases accessible from Ecology, King County, and Forterra. For this study, private is defined as privately owned land where local jurisdiction riparian buffer regulations apply. Public ROW is land that is adjacent roadways and is generally owned by the agency or jurisdiction that owns the roadway. Water body in the plat ("HYDR") is a parcel of land that has a recorded water body on the plat and contains "HYDR" in the parcel identification number; no other ownership information was found for these parcels. Protected public lands are publicly owned parcels identified in the Forterra 2009 CPS-PLDB[5]. The protection level for these parcels can vary for purposes other than natural resource conservation or ecological protection. Conservation easements are public and/or private parcels that hold a conservation easement with the property. Conservation easements were identified from data provided in the 2009 CPS-PLDB. TDRs were

[5] CPS-PLDB (2009) was acquired April 26, 2011, before their name changed from Cascade Land Conservancy. This document is unpublished and unreferenced.

identified from King County DNRP requested TDR data and TDR available on Snohomish County's website.

Data Limitations

Although there were a number of quality control and assurance steps built into the modeling process as mentioned above, there were still challenges and limitations with using the data. There were potential sources of error with the data encountered. These include:

- Although the NAIP orthophotos for 2006 and 2009 are aligned in the modeling process, there was still a small amount of photo angle and registration affecting the change results.
- When building the model, a shadow layer was developed to help mitigate the influence of shadows, atmospheric vapor, and wetness. In some change segments, the presences of shadows were falsely detected as change. In these instances, the segments were discarded after further review.
- A change segment may contain a small percentage of non-change in the polygon. In some cases, the area of non-change was the portion of segment within the riparian buffer, and therefore discarded from the results of vegetation change in the buffer.
- The model determines the presences or absence of vegetation change and cannot differentiate if restoration of a site has been done. When evaluating the results, it is beneficial to have knowledge of restoration projects that have occurred to qualify vegetation loss in this case.
- The accuracy of the riparian buffer is only as reliable as the stream data layer. In two cases, the priority stream layer did not match Ecology's GIS stream layer. For these cases, the orthophotos were used to help identify the logical path of the stream channel. In this case, the priority stream layer appeared to be off by 15 to 20-ft.

RESULTS

There were 72 land cover change segments identified within the regulatory buffers of priority stream reaches in WRIA 8. The total land cover loss is approximately 46.3 acres from 2006 to 2009 based on the 165-ft buffer (shown in Figure 2).

Results by Tiers

Summary results of total change in acres per Tiers are shown in Table 2. A complete table of results is provided in Appendix C. Overall, approximately 67 percent (30.9 acres) of land cover change within 165-ft buffer occurred inside the UGA versus 33 percent (15.4 acres) of change occurring outside the UGA.

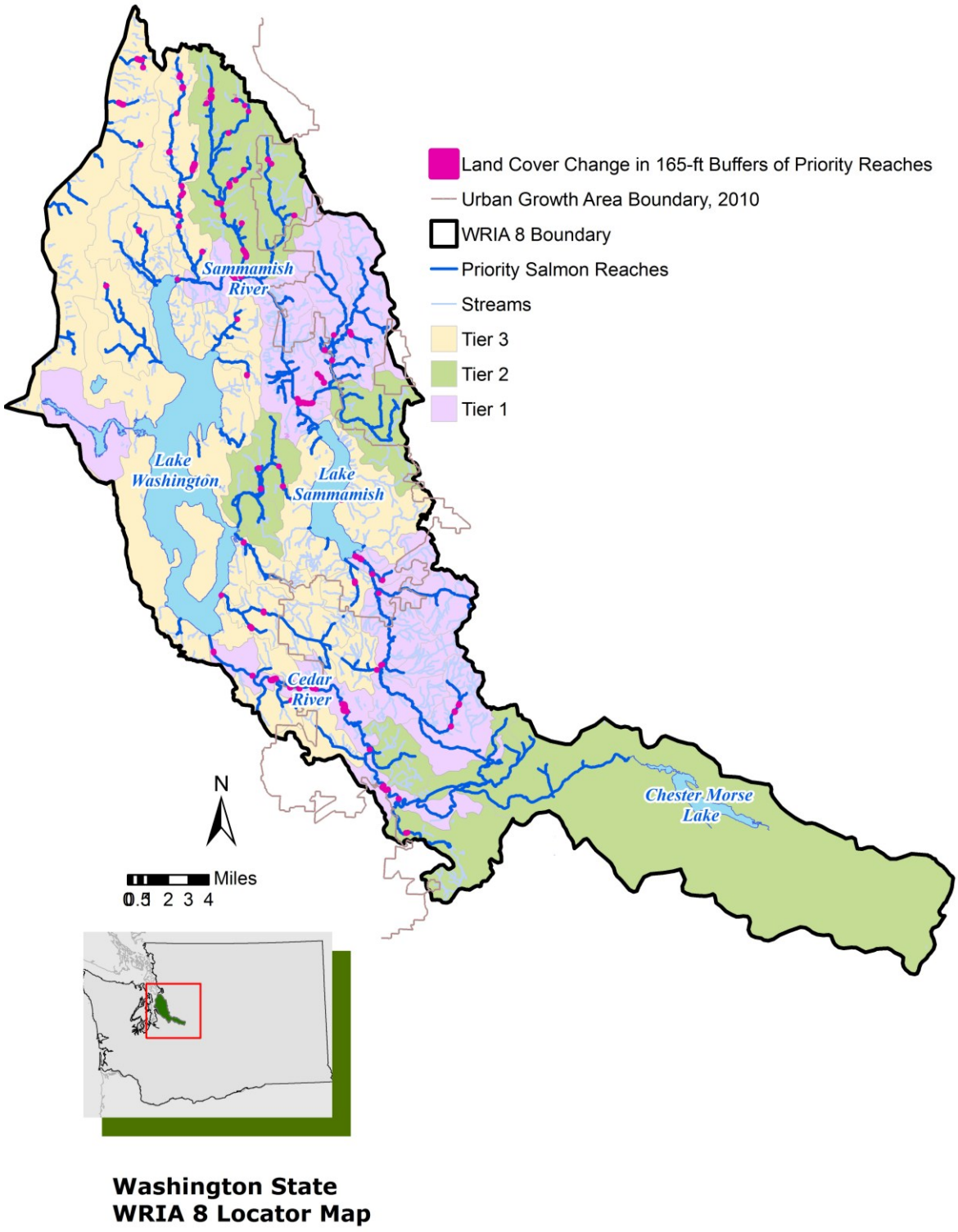

Figure 2. Land cover change segments within 165-ft riparian buffer of priority salmon reaches

Table 2. Land cover change (acres) within 165-ft riparian buffer of WRIA 8 priority stream reaches by Tier, inside and outside the UGA

Type of Change	Inside UGA (30.9 acres total)			Outside UGA (15.4 acres total)			Total per Change Classification
	Tier 1	Tier 2	Tier 3	Tier 1	Tier 2	Tier 3	
Natural Events	4.3	0	2.2	12.8	0	0	19.3
Development	2.3	1.9	8.5	0.9	0.4	0.2	14.2
Transportation Projects	5.1	2.6	2.0	0.4	0.1	0	10.2
Reduced vegetation-Human Impact	0.7	0	0	0.4	0.2	0	1.3
Public Works Project	0	0	1.3	0	0	0	1.3
Total per Tier	12.4	4.5	14.0	14.5	0.7	0.2	46.3

Predominate causes of land cover change were due to natural events, development, and transportation projects. The greatest amount of overall land cover change throughout WRIA 8 riparian buffers was due to natural events, accounting for respectively 42 percent of the change (19.3 acres). Land cover change due to natural events occurred mainly within Tier 1, outside the UGA, in the Cedar River (example shown in Figure 3). Development caused the next greatest amount of overall change, totaling approximately 31 percent (14. 2 acres). Development in Tier 3, inside the UGA accounted for the greatest amount of land cover change among the other Tiers, resulting in approximately 60 percent (8.5 acres). Transportation projects accounted for the third greatest land cover change occurring in WRIA 8 buffers, approximately 95 percent of the change occurred within the UGA, and respectively 50 percent (5.1 acres) occurring within Tier 1.

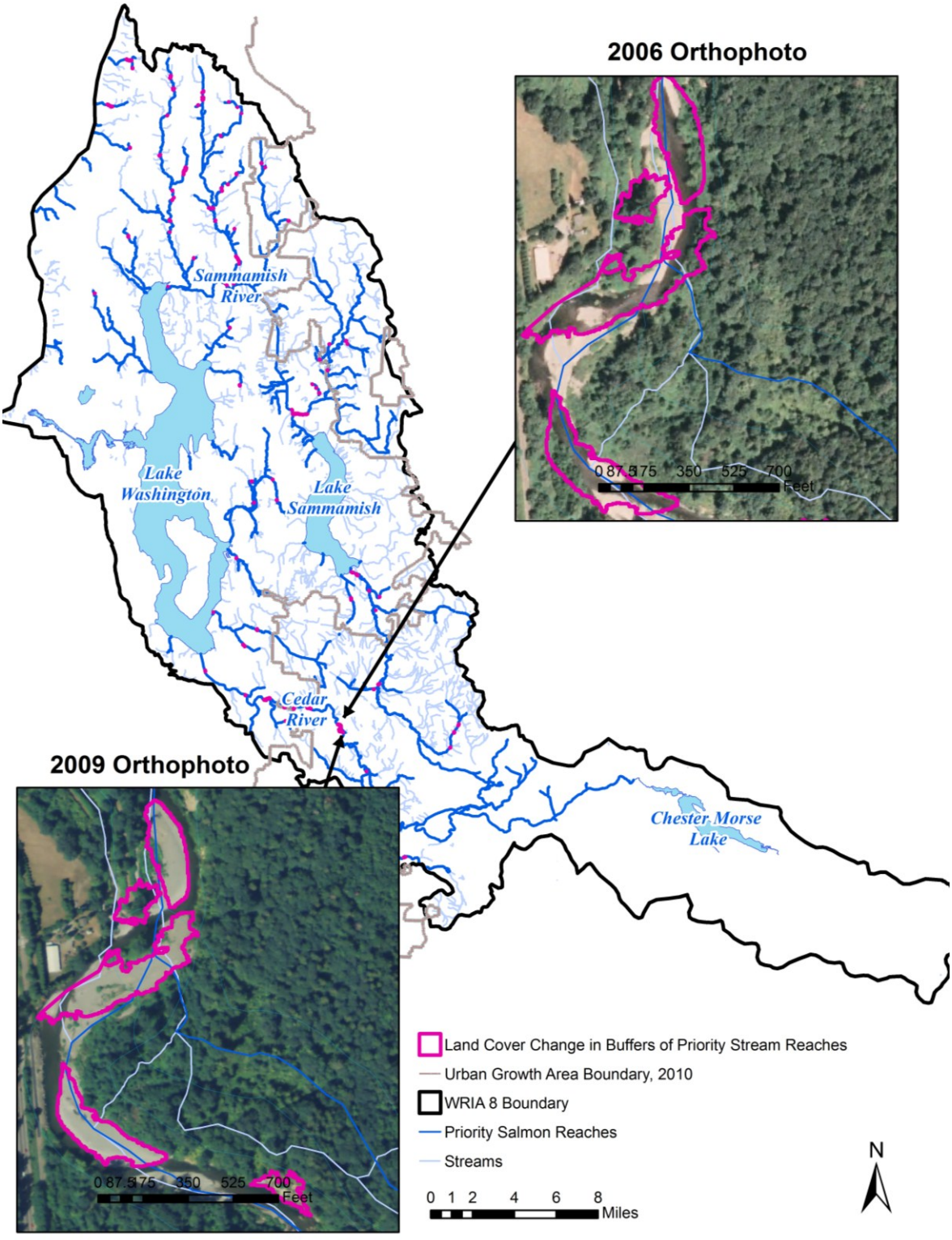

Figure 3. Land cover change segments from 2006 and 2009 orthophotos

Results by Jurisdiction

Figure 4 shows the acres of land cover change observed within in the riparian buffers of WRIA 8 jurisdictions. The greatest amount of change observed occurred in King County, outside the UGA, mainly due to natural events (12.8 acres). The greatest amount of change observed inside the UGA was due to transportation projects in Redmond (5.1 acres), mostly due to transportation work along State Route 520. The greatest amount of land cover change due to development was observed in Lynnwood associated with a Lynnwood High School and sports field development (4.6 acres); followed by natural events changing 4.3 acres of land cover in Renton, inside the UGA; and 2.6 acres of land cover change due to development in Bothell, inside the UGA.

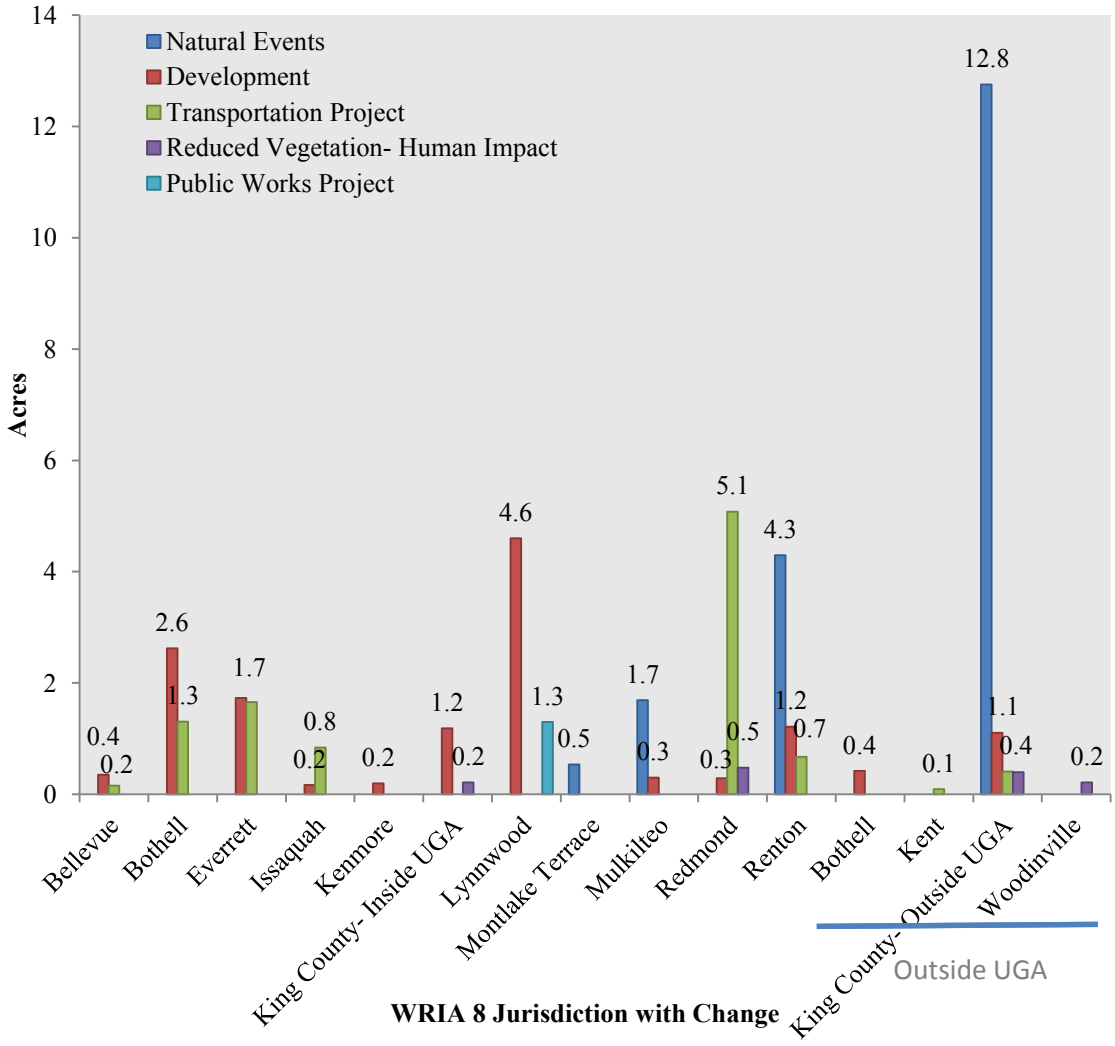

Figure 4. Land cover change (acres) within 165-ft riparian buffer of jurisdictions in WRIA 8, inside and outside the UGA

Results by Land Use Tool

The number of parcels and their land ownership type/land use tools associated with land cover change segments are shown in Table 3. Overall, there were 142 parcels with land cover change in the riparian buffers of WRIA 8. Approximately 46 percent of land cover change was on privately owned land. Land cover change on private land was mostly due to development accounting for 60 percent of the change, of which 75 percent was within the UGA. Land cover change on protected public lands represented 36 percent of the parcels associated with change segments, about half of which was due to natural events. Change associated with public ROW parcels represented 12 percent of the change segments, mainly due to transportation projects. Change on parcels identified as "HYDR" represented about 5 percent of the total parcels associated with change segments and were primarily due to natural events. Although there were only 70 parcels with conservation easement identified within a 165-ft buffer of priority streams in WRIA 8 (Table 4), no land cover changes were observed within established conservation easements. No land cover change was observed on parcels with TDRs. There were only 39 TDRs located within a 165-ft buffer of WRIA 8 priority streams.

Table 3. Number of parcels and their land ownership type/land use tool associated with land cover change classification within 165-ft riparian buffer of priority salmon reaches in WRIA 8

		Land Ownership/ Land Use Tool							
Change Classification	**Location to UGA**	**Private**	**Public ROW**	**Water body in the Plat ("HYDR")**	**Protected Lands-Public**	**Easements**	**TDRs**	**Sub-Total**	**Total**
Natural Events	Inside	0	0	1	9	0	0	10	51
	Outside	18	1	6	16	0	0	41	
Development	Inside	30	3	1	9	0	0	43	55
	Outside	10	0	0	2	0	0	12	
Transportation Project	Inside	6	12	0	8	0	0	26	28
	Outside	0	1	0	1	0	0	2	
Reduced vegetation-Human Impact	Inside	1	0	0	1	0	0	2	5
	Outside	1	0	0	2	0	0	3	
Public Works	Inside	0	0	0	3	0	0	3	3
	Outside	0	0	0	0	0	0	0	
	Total	66	17	8	51	0	0	142	142

Table 4. Number of parcels identified as protected public lands, conservation easement holders, and TDR within a 165-ft buffer of priority salmon reaches in WRIA 8 from the 2009 CPS-PLDB

Protected Public Lands	Number of Parcels
Federal	3
State	132
City or County	1,233
Total	**1,368**
Conservation Easement Holders	
Cascade Land Conservancy	16
King County	52
City of Edmonds	2
Total	**70**
TDRs	
Total	**39**

DISCUSSION

Salmon recovery in WRIA 8 as well as the Pacific Northwest depends on many factors. The most critical factor is the overall ecological health of the streams and rivers that support the salmon production. To protect further degradation of salmon spawning habitat, it is essential to protect the riparian areas from further human impact and preserve what natural, vegetated areas remain. Salmon recovery strategies recognize the importance of protecting the riparian area; however, efforts have been largely focused on short-term strategies, such as using public funds to acquire these lands along with restoration projects. In the last decade, more stringent regulatory tools and voluntary land use incentives have been established to help advance long-term strategies. These alternative approaches are new and place the management and protection in the hands of the local jurisdiction. This leads to the question: Are these alternative approaches working to advance salmon recovery goals?

The absence of land cover change in the riparian areas of parcels with conservation easements and TDRs are positive indicators that these conservation land use tools can be an effective alternative approach for advancing salmon recovery efforts. Although there were significantly fewer parcels with conservation easements and TDRs within priority buffers than the number of parcels designated as protected lands, this is an encouraging sign for future planning to increase efforts for these strategies.

Alternatively, the presence of land cover change within riparian areas located on public and private lands was more than expected. The leading causes attributed to land cover change on public and private lands can help reveal where there is concern regarding the effectiveness of current land use regulations that were established to help prevent further human related impact.

The absence of land cover change results in the riparian areas within the City of Seattle is an important finding. In the case of Seattle, the areas surrounding streams have been mostly developed prior to this study. These riparian areas still require protection from future redevelopment pressures. It may be interpreted that the City of Seattle protecting its riparian areas against redevelopment pressures and enforcing its regulatory buffers as intended.

Causes of Land Cover Change

Overall, approximately 46.3 acres of land cover change was observed in the priority buffers of WRIA 8 from 2006 to 2009. This is out of 14, 000 plus acres of 165-ft priority buffer area in WRIA 8, which equates to roughly 0.1 percent change a year or 15 acres per year. The overall predominate forces causing vegetation change within the buffers were due to natural events, development, and transportation projects (Figure 5). The predominate causes of land cover change varies from inside and outside the UGA. Inside the UGA, development is the leading cause of change followed by transportation projects and natural events. It is significant to see development and transportation projects as leading causes of change inside the UGA. The UGA was established to accommodate growth and development within its boundaries; however, current regulations should be providing protection from these development land use pressures.

Outside the UGA, the leading cause of land cover change is natural events, followed far behind by development, reduced vegetation from human impact, and transportation projects. It was expected to see natural events as a leading cause for change outside the UGA, as there is more intact floodplain for the stream channel to migrate.

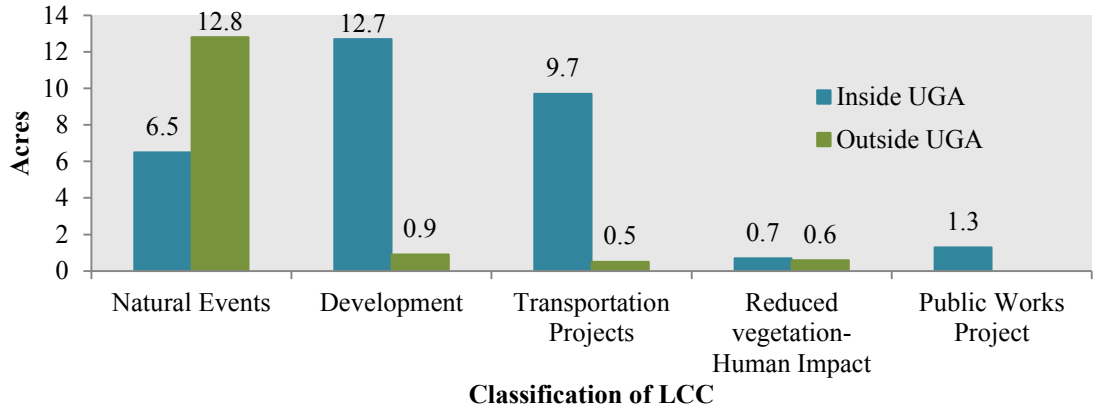

Figure 5. Classification of land cover change (acres) within 165-ft riparian buffer of priority salmon stream reaches in WRIA 8, inside and outside the UGA

Land Cover Change and Land Use Tools

A review of land cover change and associated land ownership/land use tools show that most change was due to development located on private property, as shown in Figure 6. All WRIA 8

local jurisdictions have established regulatory provisions for protecting the riparian buffers; however, some mitigation of the buffers is acceptable, as described above in Section 2. The intention for buffer mitigation is to ensure no net loss of critical salmonid habitat function, while preventing unnecessary hardship on the property owner and allowing some flexibility for the local jurisdiction to use the land. Findings from this study raise concerns for the cumulative impacts this approach will continue to have on the buffer and how much buffer mitigation should be acceptable.

It is possible that some developments in the riparian buffer were permitted through accepted mitigation or by vested development rights (i.e., grandfathered in and not subject to the more stringent critical areas protection later adopted), or that the development was conducted illegally. For example, the noted land cover change due to development in Bellevue was attributed to a property owner that illegally encroached on the riparian buffer. The violation was discovered and the owner was required to replant the area under code enforcement (City of Bellevue staff conversation with me; unreferenced).

Protected public lands were the next leading land ownership type associated with land cover change in the priority buffers of WRIA 8. With natural events excluded, development and transportation projects were the leading causes of change on public protected lands. There are different levels of protection provided for public lands. For these public lands, they were managed for purposes other than natural resource conservation or ecological protection[6].

When evaluating land ownership/land use tool and the protection of the riparian buffer, the flexibility in the approach to managing riparian buffers makes it difficult to determine if riparian buffer regulations are providing sufficient protection to both private and public protected lands. When evaluating public protected lands and the protection of the riparian buffer, public lands provide better protection to the buffer from development compared to private land ownership. Protected public lands provided less protection from transportation projects than private ownership; however, the protected public lands were not established for the sole purpose of natural or ecological conservation. In this way, competing objectives for public lands can compromise salmon habitat.

[6] Level of protection for public lands defined in the 2009 Central Puget Sound Protected Lands Database (CPS-PLDB) provided by Forterra in 2011.

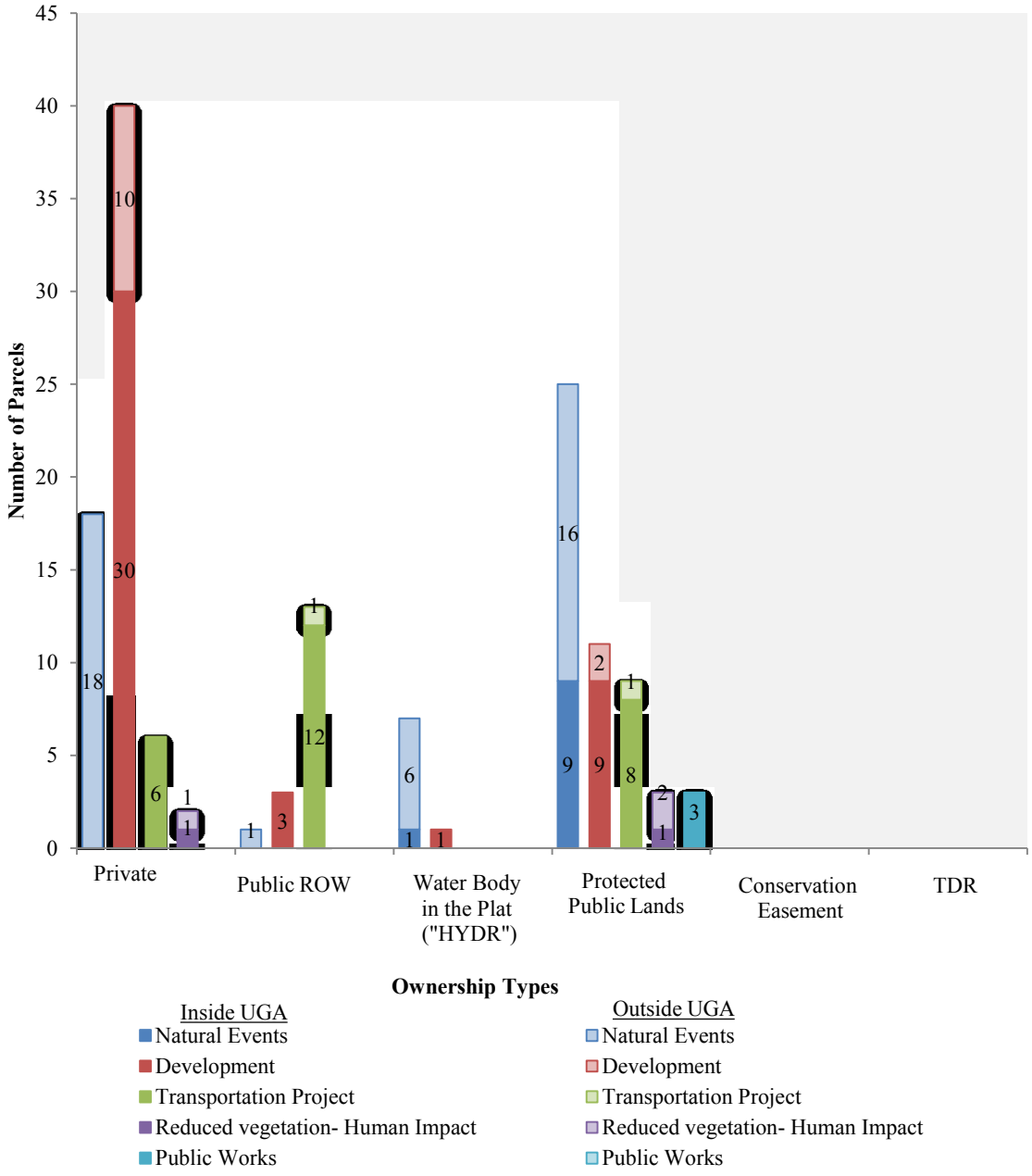

Figure 6. Number of parcels associated with land cover change within 165-ft riparian buffer and their land ownership/land use tool

Concurrent with this study, Vanderhoof et al. (2011) examined land cover change in riparian buffers along priority streams in WRIA 8 using orthorectified photographs from 2005 and 2009.

Vanderhoof et al. analyzed only a random sample of Tier 1 and Tier 2 priority subbasins in WRIA 8 and used an expanded time series. In their findings, some riparian areas inside the UGA lost forest cover and all gained impervious cover between 2005 and 2009. Similarly, this study has observed more land cover change inside the UGA than outside.

The land cover change model used in this study is a useful tool to evaluate change observed across the entire WRIA. However, evaluating change in each jurisdiction's regulatory buffer presented several challenges. When using aerial imagery and data layers created in GIS, it is important to realize limitations on the precision of the data. The accuracy of streams mapped influences the location of the buffer width and thus influences the number of change segments observed in the buffer. Further, it is difficult to determine effectiveness when there are different management approaches for applying regulatory buffer widths (i.e., buffer averaging, two-three zone buffers, buffer enhancement/reduction).

Recommendations for Future Actions

Based on results of this study, the following are recommendations for future actions and questions to address in later studies:

- Continue to rely on regulatory riparian buffers and conservation land use tools available for riparian buffer protection. Allow more time to see how regulations are working.
- Work with local jurisdictions to provide "Best Available Science" on effectiveness of single buffer versus multiple buffers.
- Target outreach resources towards private property owners along lower priority stream reaches for opportunities to establish conservation easements and TDRs. Continue to evaluate the effectiveness of these voluntary land use tools.
- Identify where riparian buffer modifications/mitigation has occurred and evaluate if this management approach is working as intended.

The utility of this study can be applied to other WRIAs in Washington State and for an expanded time period, as 2011 aerial imagery is currently available. Pierce has recently acquired funding to map vegetation change with remote sensing data from 2006, 2009, and 2011 for all WRIAs in Puget Sound. Pierce's model will provide consistent, quick results that are informative "right out of the bag". Using Pierce's results to evaluate land cover change occurring in the

riparian buffers and what land use tools are at play, as such in this study, will help inform salmon recovery strategies and help local and regional planners better understand the land use activities occurring on a broader level. Overall, the results can help incorporate transparency and accountability for protecting our riparian areas.

REFERENCES

Castelle AJ, Johnson AW, Conolly C. 1994. Wetlands and stream buffer size requirements- a review. Journal of Environmental Quality 23: 878-82.

Cox W. 2011. The evolving urban area: Seattle [Internet]. [cited 2012 Oct 15]. Available from: http://www.newgeography.com/content/002312-the-evolving-urban-area-seattle

Dana A, Ramsey M. 1989. Conservation easeemnts on the common law. Stan. Envtl. L. J. 8(2): 2-45.

[FISRWG] Federal Interagency Stream Restoration Working Group. 1998. Stream corridor restoration: principles, processes, and practices. Washington DC. PB98-158348LUW.

Fishburn IS, Kareiva P, Gaston KJ, Armsworth PR. 2009. The growth of easements as a conservation tool. PLoS ONE 4, no. 3.

Freilich RH, Davis LK. 1981. Saving the land: the utilization of modern techniques of growth mangment to preserve rural and agricultural America. Urb Law 13(27): 29.

Greene JD, Richmond TC, Greene G, Greenwalt T. 2009. Conservation tools: an avaluation and comparison of the use of certain land preservation mechanisms. Prepared for Washington State Recreation and Conservation Office. Pursuant to SHB 1957. 86.

[GSRO] Governor's Salmon Recovery Office. 2000. State of salmon: a leport to the Legislature. Submitted by the Office of the Governor in fulfillment of requirements in RCW 77.85.020 [Internet]. [cited 2012 Sep 23]. Available from: http://www.rco.wa.gov/documents/gsro/2000_State_of_Salmon.pdf

Haberstock AE, Nichols HG, DesMeules MP, Wright J, Christensen JM, Hudnut DH. 2000. Method to identifying effective riparian buffer widths for Atlantic salmon habitat protection. J. Am. Water Resour. Assoc. 36(6): 1271-86.

[HWS] Habitat Work Schedule. Salmon habitat conservation - WRIA 8 [Internet]. [cited 2012 Jun 1]. Available from: http://hws.ekosystem.us/?p=Page_89901fef-078a-47c8-9c7b-f3c0c259700a&sid=240

Herrara Environmental Consultants. 2005. 2005 best available science (BAS) review. Prepared for City of Bellevue. Bellevue, WA.

[IMST] Independent Multidisciplinary Science Team. 2002. Recovery of wild salmonids in western Oregon lowlands. Governor's Natural Resources Office, Technical report to 2002-1 to the Oregon plan for salmon and watersheds, Salem, OR.

King County. 2004. Best available science, volume 1: a review of science literature: critical areas, stormwater, and slearing and grading proposed ordinances. King County Executive Report.

King County. 2005. Critical areas ordinance user's manual. Department of Development & Environmental Services [Internet]. [cited 2012 Jun 11]. Available from: http://www.kingcounty.gov/property/permits/codes/CAO.aspx

Knutson KC, Naef LF. 1997. Management recommendations for Washington's priority habitats: riparian. Washington Department of Fish and Wildlife, Olympia.

[LTA] Land Trust Alliance. 2008. Basic facts and resources for landowners: conservation easements. Fact Sheet. Washington, DC.

Leavitt J. 1998. The functions of riparian buffers in urban watersheds [thesis]. [Seattle (WA)]: University of Washington.

Leonetti FE, Paulsen K, Murray B. 2005. Watershed evaluation and Identification of Chinook salmon Tier 1, 2, and 3 subbasins supporting salmon conservation planning in WRIA 8. Appendix C-2, WRIA 8 Chinook Conservation Plan (Volume III). WRIA 8 Technical Committee.

Lombard J. 2003. The politics of salmon recovery in Lake Washington. In: Bolton S, Booth DB, Wall L, Montgomery DR, editors. Restoration of Puget Sound rivers. Seattle, WA: University of Washington Press. 174-193.

May CW. 2003. Stream-riparian ecosystems in the Puget Sound Lowland eco-region: a review of best available science. Watershed Ecology LLC, Kitsap County, WA.

May CW, Horner RR. 2000. The cumulative impacts of watershed urbanization on stream-riparian ecosystems. AWRA Riparian Ecology and Management in Multiland Use Watersheds Conference. Portland, OR.

Miller AJ. 1999. Transfer of developmet rights in the constitutional landscape: as Penn Central failed to wheather the storm? Nat. Resources J 39: 459.

Montgomery DR, Booth DB, Bolton S. 2003. Puget Sound rivers and and salmon recovery. In: Bolton S, Booth DB, Wall L, Montgomery DR, editors. Restoration of Puget Sound rivers. Seattle, WA: University of Washington Press. Seattle, WA: University of Washington Press. 1-13.

Morley SA. 2000. Effects of urbanization on the biolgoical integrity of Puget Sound lowlands streams: Restoration with a biological focus [thesis]. [Seattle (WA)]: University of Washington.

[MRSC] Municipal Research and Services Center of Washington. 2010. Flexibility in environmental regulations [Internet]. [cited 2012 Sep 23]. Available from: http://www.mrsc.org/subjects/planning/flexenviron.aspx#buffer

[NMFS] National Marine Fisheries Service. [date unknown]. Puget Sound Chinook ESA salmon recovery plan [Internet]. National Oceanic and Atmospheric Administration Northwest Regional

Office. [cited 2012 Oct 13]. Available from: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm

[NMFS] Northwest Indian Fisheries Commission. 2011 Implementation status assessment final report (Puget Sound Chinook Salmon Recovery Plan). Millie M. Judge, Lighthouse Natural Resource Consulting, Inc. Everett, WA.

NMFS. 2012. 2012 State of our watersheds report [Internet]. [cited 2012 Oct 13]. Available from: http://maps.nwifc.org:8080/SOW2012/SOW_Doc/PDFs/0_2012_SOWRpt.pdf

Pierce, KB Jr. 2012. High resolution change detection with remote sensing for Puget Sound. Presentation for the Pacific Northwest Aquatic Monitoring Partnership (PNAMP).

[RCR] Ruckelshaus Center Report. 2008. The shared strategy for Puget Sound: a description and initial assessment of collaborative salmon recovery planning in Washington [Internet]. [cited 2012 Oct 13]. Available from: http://pcc.wsu.edu/projects/documents/SharedStrategyFinalReport-summaryonly.pdf

Stormwater Center. 2004. Aquatic buffers fact sheet: buffer zones [Internet]. [cited 2012 Sep 23]. Available from: http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool3_Buffers/BufferZones.htm

[USDA FSA] US Department of Agriculture Farm Service Agency. 2011. NAIP imagery [Internet]. [cited 2012 Feb 8]. Available from: http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai

Vanderhoof J, Stolnack S, Rauscher K, Higgins K. 2011. Lake Washington/Cedar/Sammamish watershed (WRIA 8) land cover change analysis. Seattle, WA: Prepared for WRIA 8 Technical Committee by King County Water and Land Resources Division, Department of Natural Resources and Parks.

Walker J. 2012. What are NPGE and NGPA designations on property [Internet]? [cited 2012 Jun 13]. Available from: http://site-studio.com/blog/?p=32

[WA Dept. Community Dev.] Washington State Department of Community Development Growth Management Div. 1992. Issues in designating urban growth areas part 1[Internet]. [cited 2012 Sep 23]. Available from: http://www.commerce.wa.gov/DesktopModules/CTEDPublications/CTEDPublicationsView.aspx?tabID=0&alias=CTED&lang=en&ItemID=1074&MId=944&wversion=Staging

[WA DCTED] Washington State Department of Community, Trade and Economic Development. 2003. Critical areas assistance handbook: protecting critical areas within the framework of the Washington Growth Management Act [Internet]. [cited 2012 Oct 12]. http://www.commerce.wa.gov/DesktopModules/CTEDPublications/CTEDPublicationsView.aspx?tabID=0&alias=CTED&lang=en&ItemID=976&MId=944&wversion=Staging

[WA DOE] Washington Department of Ecology. 2001. Fact sheet: riparian areas. 00-10-023. Water Quality Program [Internet]. [cited 2012 Jun 11]. Available from: https://fortress.wa.gov/ecy/publications/publications/0010023.pdf

[WRIA 8 SC] WRIA 8 Steering Committee and Forum. 2005. Lake Washington/Cedar/Sammamish watershed (WRIA 8) Chinook salmon conservation plan. Vol. I. Seattle, WA.

Appendix A. WRIA 8 Jurisdictions Regulatory Riparian Buffers

Jurisdiction	Researched Regulatory Buffer Width	Notes	Presence of Land Cover Change 2006-2009
Town of Beaux Arts Village	Not available.	No salmon streams in jurisdiction.	
City of Bellevue	Type F= 100' undeveloped, 50'developed site. Kelsey Creek and WestTributary=50' plus structure setbacks.	Allow buffer averaging. No data on buffer reduction/enhancement.	x
City of Bothell	Type F= 100'	Allow buffer averaging and buffer reduction/enhancement.	x
City of Clyde Hill	Not available.	No salmon streams in jurisdiction.	
City of Edmonds	Type F= 150'	Allow buffer averaging and buffer reduction/enhancement.	x
Town of Hunts Point	Not available.	No salmon streams in jurisdiction.	
City of Issaquah	Class 2= 100'	Allow buffer averaging and buffer reduction/enhancement. Additional building setback may apply.	x
City of Kenmore	Type 1= 150', min=112.5' Type 2= 100',min=75'	Type 1 includes Sammamish River and Little Swamp Creek. Type 2 streams with salmonid use. Reduction/enhancement allowed. No data on buffer averaging.	x
City of Kent	Type 2= 100'	Allow buffer averaging and buffer reduction/enhancement.	x
King County-Rural- outside UGA	165'	For basins in UGA and designated as "high" on Shoreline Map=165'. Allow buffer averaging and buffer reduction/enhancement.	
King County-Urban-inside UGA	115'/165'		x
City of Kirkland	Class A= 75'	Allow buffer averaging and buffer reduction/enhancement.	x
City of Lake Forest Park	Type 1=115', min 70'	Allow buffer averaging and buffer reduction/enhancement. Only three stream types available.	
City of Maple Valley	100'	Allow buffer averaging. Buffer enhancement allowed with non-development proposals.	x

Jurisdiction	Researched Regulatory Buffer Width	Notes	Presence of Land Cover Change 2006-2009
City of Medina	Type 1= 100', min 50'	Allow buffer averaging and buffer reduction/enhancement.	
City of Mercer Island	Type 1 watercourse= 75', 37' with enhancement	Allow buffer averaging and reduction/enhancement	
City of Mill Creek	North Creek and Tambark Creek 150 feet All other streams 75 feet	The buffer width is not reduced to less than 50 percent of the standard width. In no case shall the reduced buffer be less than 25 feet.	x
City of Mountlake Terrace	Class I= (shorelines of state) 150', plus 75' for threatened species, plus 15 for building setback (150' to 240') Class II= 100', plus 50' for threatened species, plus 15' for building setback (100' to 165')	Allow buffer averaging and buffer reduction/enhancement on Class II and lower, but not more than 25% in one location.	x
City of Mukilteo	Type 3= 150'	Allow buffer averaging and buffer reduction/enhancement.	x
City of Newcastle	Class 2= 100'	Allow buffer averaging and buffer reduction/enhancement.	
City of Redmond	Class 1= 150', plus 50' structure setback. Class 2= 100' plus 50'structure setback.	Allow buffer averaging and reduction/enhancement	x
City of Renton	Class I= 200' Class 2- 100'	Allow buffer averaging and buffer reduction/enhancement, and shoreline conditional use permits.	x
City of Sammamish	Type S/F= 150'	Allow buffer averaging and buffer reduction/enhancement.	
City of Seattle	Shoreline=75-100' Type 2=75'		
City of Shoreline	Type 1= 150', 115' for enhancement Type 2=115', 75' for enhancement	Allow buffer averaging and buffer reduction/enhancement.	
Snohomish County	Type s/f= 150'	Allow buffer averaging and buffer reduction/enhancement.	x
City of Woodinville	Type 1= 150', with reduced buffer enhancement=115'(but can go as low as 100' if buffer functions same) Type 2= 115', with reduced buff enhancement=100'	Allow reduced buffer enhancement. Not determined if buffer averaging is available.	x
Town of Yarrow Point	Not available.	Not available.	

Jurisdiction	Researched Regulatory Buffer Width	Notes	Presence of Land Cover Change 2006-2009
City of Everett	Type F= 100' for sites with intact native vegetation, 150' for sites with un-vegetated, sparse, or invasive vegetation.	Allow buffer averaging and buffer reduction/enhancement.	x
Lynnwood	Cat I-100' CatII- 60'	Cat1= Scribber Cr., Swamp Cr., Lunds Cr., Halls Cr. Cat2= other fish bearing streams. Allow reduced buffer averaging and buffer reduction/enhancement.	x

Appendix B. List of GIS Data sources

The following is a list of the publicly available GIS data sources and the layer names used in this analysis.

King County GIS Data Portal [accessed 2012 Feb 10]. Available from: http://www5.kingcounty.gov/gisdataportal/Default.aspx.

-Parcels. Polygon feature class. Contains countywide coverage of property, tax parcel, and parcels.

- Public Lands. Polygon feature class. Contains publicly-owned parcels from the SDE spatial view PARCEL_COMMONDATA_ARA_VIEW.

-Right of Way. Polygon feature class. Contains polygons of right of ways countywide.

-Urban Growth Areas for King County. Polygon feature class. Contains the urban growth boundaries for King County.

-King County Streams. Line feature class. Streams of King County and surrounding areas.

-King County Incorporated Areas. Polygon feature class. Contains boundaries of incorporated areas in King County.

-King County Political Boundary. Polygon feature class. Contains King County boundary.

-Municipal Watersheds in King County. Polygon feature class. Contains the boundaries for King County Municipal Watersheds.

-Transportation. Polyline feature class. Contains transportation features including rail, trails, and pedestrian walkways.

Snohomish County Integrated Lands Records Data CD [accessed 2012 Feb 10]. County FTP site available: ftp://ftp.snoco.org/assessor/shapefiles.

- Parcels. Polygon feature class. Contains countywide coverage of property, tax parcel, parcels, and land use.

-Easements. Polygon feature class. Contains the easement data for ingress-egress, utility, drainage, etc. across parcels in Snohomish County. Does not depict all easements of legal record.

-Transfer of Development Rights (TDR). Polygon feature class. Contains TDR boundaries within Snohomish County.

-Roads. Line feature class. Contains roads and right of way boundaries in Snohomish County.

-Urban Growth Boundary. Line and polygon feature classes. Contains the boundaries for the urban growth areas in Snohomish County.

-Cities. Polygon feature class. Contains the boundaries of cities in Snohomish County.

-Waterbodies. Polygon and line feature classes. Contains the boundaries of water features of cadastral significance. Not intended to be a complete hydrography data set for Snohomish County.

-County Boundary. Polygon feature class. Contains the boundary of Snohomish County.

Washington Department of Ecology GIS Data [accessed 2012 Feb 10]. Available from: http://www.ecy.wa.gov/services/gis/data/data.htm.

-Water Resource Inventory Areas (WRIA). Polygon feature class. Contains the boundaries given for Washington State WRIAs.

-Washington State Basemap. Polygon feature class. Contains the boundary of Washington State and water features.

Other GIS data was provided upon request:

National Ag. Imagery Program Mosaic (NAIP Imagery). 2006 and 2009 Orthophoto Imagery Mosaics for Snohomish County and King County. Available from: http://datagateway.nrcs.usda.gov/GDGOrder.aspx.

Forterra (formerly The Cascade Land Conservancy). 2009 Central Puget Sound Protected Lands Database (CPS-PLDB), unpublished. A geospatial database of protected lands and conservation easements received via email April 26, 2011.

Salmon Habitat Work Schedule Group. Provided GIS data on land acquisitions and salmon habitat restoration project work within WRIA 8 received via email April 18, 2011.

King County Water and Land Resources Division Department of Natural Resources and Parks. Provided geospatial data specific to WRIA 8 priority salmon stream reaches received via email correspondence April 1, 2011.

King County Department of Natural Resource Protection (DNRP). Provided geospatial data on transfer of development rights in King County received via email April 8, 2011.

Appendix C. Total land cover change results (acres) within 165-ft riparian buffer of priority salmon stream reaches per jurisdiction, Tier, and inside/outside the UGA

	Natural Event	Develop-ment	Trans. Project	Human Disturbance	Public Works	Total
Inside the UGA						
Bellevue						
Tier 2		0.4				0.4
Tier 3			0.2			0.2
Sub-total		**0.4**	**0.2**			**0.5**
Bothell						
Tier 1		0.2				0.2
Tier 2		1.5	1.3			2.8
Tier 3		0.9				0.9
Sub-total		**2.6**	**1.3**			**3.9**
Everett						
Tier 2			1.3			1.3
Tier 3		1.7	0.4			2.1
Sub-total		**1.7**	**1.7**			**3.4**
Issaquah						
Tier 1		0.2				0.2
Tier 3			0.8			0.8
Sub-total		**0.2**	**0.8**			**1.0**
Kenmore						
Tier 3		0.2				0.2
Sub-total		**0.2**				**0.2**
King County						
Tier 1		1.2		0.2		1.4
Sub-total		**1.2**		**0.2**		**1.4**
Lynnwood						
Tier 3		4.6			1.3	5.9
Sub-total		**4.6**			**1.3**	**5.9**
Montlake Terrace						
Tier 3	0.5					0.5
Sub-total	**0.5**					**0.5**
Mulkilteo						
Tier 3	1.7	0.3				2.0
Sub-total	**1.7**	**0.3**				**2.0**

	Natural Event	Develop-ment	Trans. Project	Human Disturbance	Public Works	Total
Inside the UGA (continued)						
Redmond						
Tier 1		0.3	5.1	0.5		5.8
Sub-total		**0.3**	**5.1**	**0.5**		**5.8**
Renton						
Tier 1	4.3	0.5				4.8
Tier 3		0.7	0.7			1.4
Sub-total	**4.3**	**1.2**	**0.7**			**6.2**
Outside the UGA						
Bothell						
Tier 2		0.4				0.4
Sub-total		**0.4**				**0.4**
Kent						
Tier 2			0.1			0.1
Sub-total			**0.1**			**0.1**
King County						
Tier 1	12.8	0.9	0.4	0.4		14.5
Tier 3		0.2				0.2
Sub-total	**12.8**	**1.1**	**0.4**	**0.4**		**14.7**
Woodinville						
Tier 2				0.2		0.2
Sub-total				**0.2**		**0.2**
Grand Total	**19.3**	**14.2**	**10.2**	**1.3**	**1.3**	**46.3**

Note:

1. For WRIA 8 jurisdictions not listed in this table, land cover change was not observed within the jurisdiction's regulatory riparian buffer of priority salmon stream reaches.
2. Blanks are zeros.