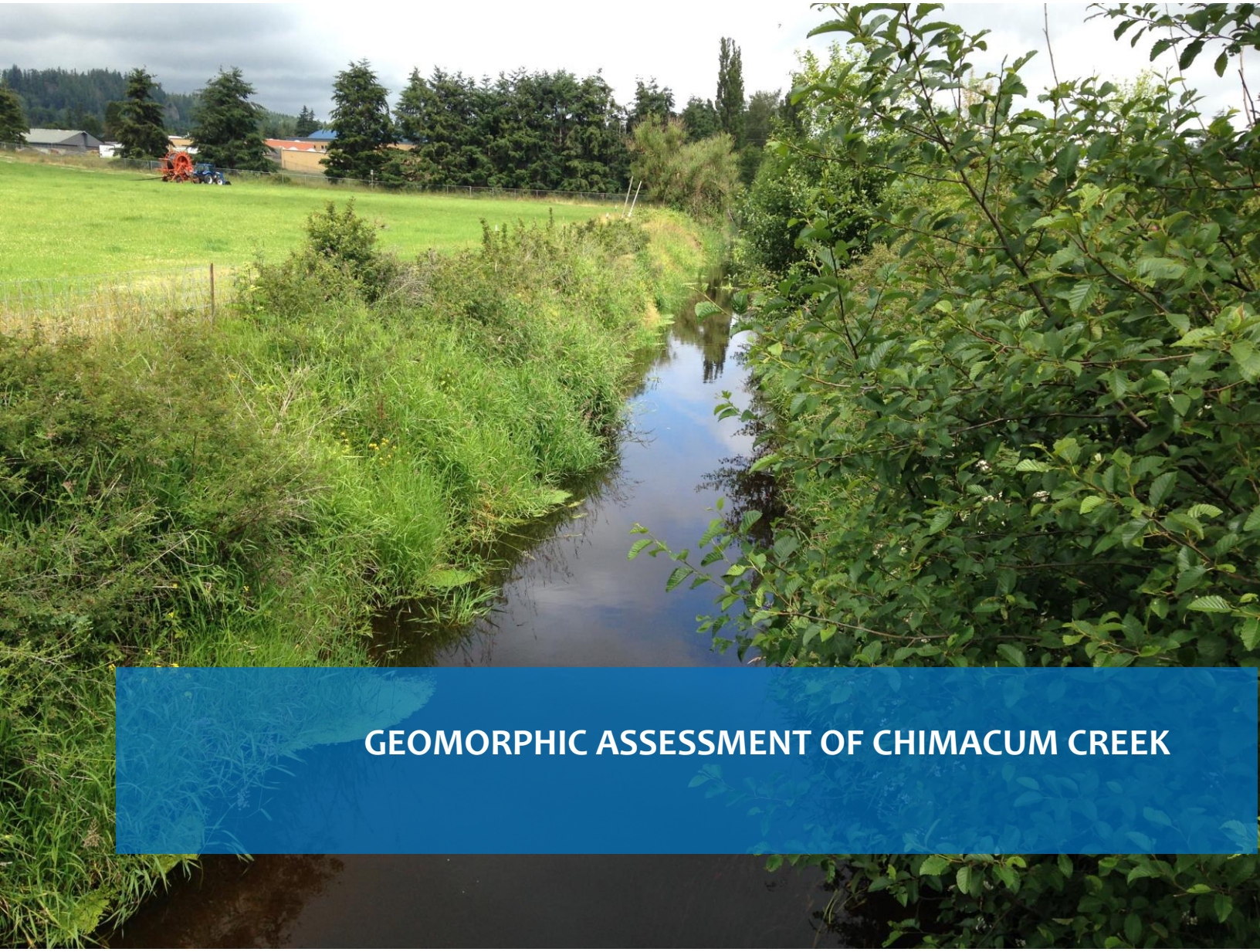


GEOMORPHIC ASSESSMENT OF CHIMACUM CREEK

North Olympic Salmon Coalition
205 W Patison St. b,
Port Hadlock, WA 98339
360.379.8051

Natural Systems Design
1900 N. Northlake Way, Suite 211
Seattle, WA 98103

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

LIST OF APPENDICES

THIS PAGE INTENTIONALLY LEFT BLANK

1. INTRODUCTION

The North Olympic Salmon Coalition (NOSC) requested that Natural Systems Design (NSD) conduct a geomorphic assessment of Chimacum Creek, in east Jefferson County, Washington. This assessment is intended to analyze and synthesize the physical components that contribute to river function, in order to better understand how to address fish habitat, water quality impairment, and frequent flooding issues in the watershed. Land ownership, stakeholder perspectives on land use priorities, and economic factors are all major considerations for watershed planning or restoration actions, but are not included in this analysis. The goal of this assessment is to provide a physical baseline as a starting point for future planning efforts.

Chimacum Creek includes two main forks, main stem Chimacum Creek (also called west fork) and east fork Chimacum Creek, which join at approximately RM 2.9 and flow to the outlet into Port Townsend Bay (RM 0.0) (Map 1). The assessment focuses on the agricultural river valley that extends from approximately the confluence of the two forks at RM 2.9 to RM 10.0 on the main stem and RM 5.5 on the east fork, with some consideration given to the headwaters and tributaries.

Chimacum Creek is home to native Coho, summer chum, and steelhead, and fish populations have been impacted by degradation of the stream. Coho returns exhibited a slight decreasing trend from 1998-2013 (Gately, Clarke, Ecelberger, & Schrader, 2015), and there are conflicting assessments of the health of the population (Correa, 2002). Summer chum were reestablished after extinction with Discovery Bay summer chum stock and the first adults returned in 1999 (Correa, 2002). Prior restoration actions have focused on addressing blockages to fish passage, impaired water quality, and the limited availability of suitable habitat. Some barriers have been removed or upgraded (Smayda Environmental Associates, 2001), but remaining barriers, impaired water quality, and degraded habitat continue to be limiting factors for salmon populations.

The Chimacum Creek valley has a rich agricultural history is a valued local resource for food production. Key issues of concern to agricultural stakeholders in the valley include frequent overbank flooding or perennial inundation from high groundwater of some adjacent agricultural fields, invasive reed canary grass, and the re-establishment of beaver activity, which impacts riparian vegetation and flooding.

This technical memo describes assessment of the spatial relationships between water quality issues and geomorphic features in Chimacum Creek, in order to prioritize future analyses and restoration efforts. We draw on previously collected point data and publicly available spatial data to identify opportunities for restoration and key data gaps.

2. WATERSHED ASSESSMENT

2.1 Background

2.1.1 Historic and Current Conditions

Historically, the Chimacum Creek valley was a vegetated, low gradient alluvial valley with substantial wetlands (Figure 1, from Bahls & Rubin (1996)). Government Land Office (GLO) surveys were conducted between 1858-1974 and notes and maps indicate extensive riparian forests, swamps, wet prairies and beaver ponds, and the morphology of the creek and valley were likely strongly controlled by beaver-created floodplain water bodies (Bahls & Rubin, 1996). Over 2000 acres of the valley consisted of wetlands, including almost 600 acres that were perennial water bodies suitable for both summer and winter fish rearing (Table 1 and Map 2; Bahls & Rubin (1996)). In the early 1900s the floodplain forest was removed and the land was

converted to agricultural use. The creek was ditched and straightened in the 1940s, commonly using black gun powder during salmon migration season to establish the ditch (Bahls & Rubin, 1996). Drainage tiles were also installed in an effort to further dry the land for agriculture. As a result, all channel form complexity and side channels were eliminated and channel length reduced. Bahls & Rubin (1996) estimate a minimum channel length reduction of approximately 25% based on comparing channel maps from 1919 and 1995, but since agricultural conversion began in the 1850s, the 1919 map likely does not show many historic channels (Table 1). Today, less than 50% of the historic wetlands area is still classified as wetland (Homer et al., 2015), and much of this wetland area is marginal agricultural land that is likely to be seasonally inundated.

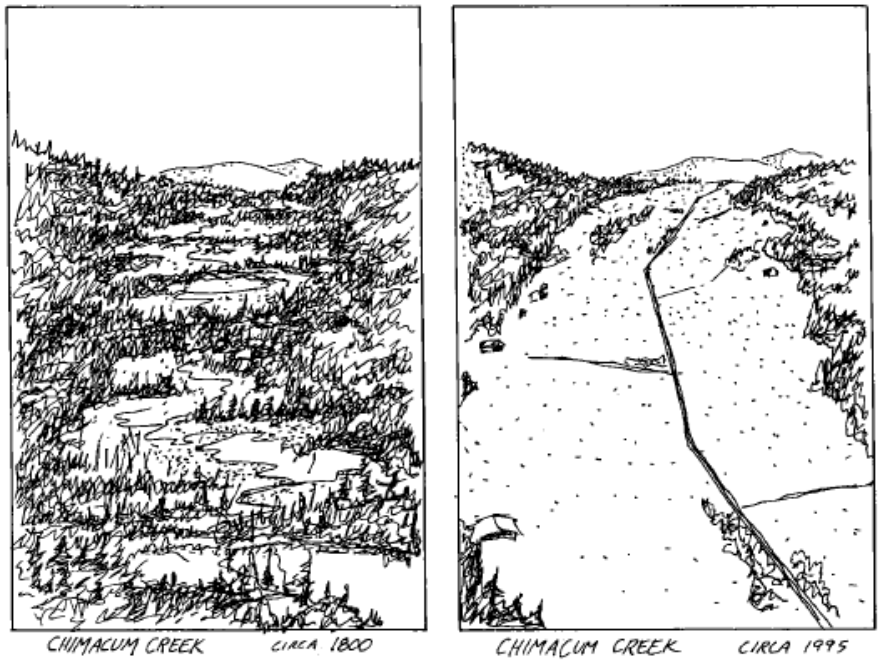


Figure 1. Illustration of the Chimacum Creek watershed looking upstream along the main stem showing (left) historic conditions (circa 1800) which included riparian forest, beaver ponds, and channel complexity and (right) current conditions (circa 1995) after riparian forest removal and channel straightening and ditching. From (Bahls & Rubin, 1996), based on GLO survey data.

Together, these modifications have impacted fish habitat, water quality, and geomorphic function of the creek. The availability of both spawning and rearing habitat have declined; Bahls & Rubin (1996) estimated that only 6% of summer rearing habitat, 3% of winter rearing habitat and 88% of spawning habitat remains relative to the 1850s. They further quantified geomorphic features that are critical for fish habitat, and found low pool frequency and size, low wood frequency and size, and low availability of spawning gravels. During sampling over the summer of 1995, average pool depth was less than 0.5 m, and average abundance of large wood was less than 5 pieces per 100 m (with no large wood at 50% of sample locations)(Map 3; data from (Bahls & Rubin, 1996)).

Table 1. Comparison of historic versus current conditions of river components within the Chimacum Creek valley.

RIVER COMPONENT	HISTORIC	CURRENT	PERCENT REDUCTION	INFORMATION SOURCE
Wetlands	2240 acres (1650 inundated in the winter only and 590 inundated year-round)	904 acres of wetland (classified by the NLCD) within the historic footprint, much of which is located on agricultural properties	>60%	Spatial analysis of (Bahls & Rubin, 1996) and (Homer et al., 2015)
River channel length	27.2 miles	21.7 miles	>20%	Based on winter rearing habitat length reported in Table 4 of (Bahls & Rubin, 1996)
Riparian Forest	Unknown, but very high before agricultural conversion	56% of main channels has some riparian vegetation in various stages of maturity after re-planting	>44%	Spatial analysis of (USDA, 2015)
Agricultural ditches within valley bottom	Unknown tributary lengths; no agricultural ditches	Approximately 42 miles of tributary/distributary ditches within valley bottom, 31% has some riparian vegetation	Unknown	Spatial analysis of (USDA, 2015)

Water quality is impaired in many locations, with measured exceedances of temperature, dissolved oxygen (DO), and fecal coliform standards in many locations (Map 6 and Mapbook 1, data from Jefferson County Conservation District; (Gately et al., 2015)). Recent analyses documents a weak declining trend in temperature and DO exceedances, and suggests that locations with the most improvement are downstream from well-established riparian vegetation (Gately et al., 2015). Fecal coliform concentrations have generally declined in the watershed, and sampling data suggest that there are multiple sources, including septic tanks, agriculture, and birds. This assessment focuses on temperature and DO, which are more clearly tied to geomorphic and riparian factors; for a full discussion of water quality data and trends, see (Gately et al., 2015).

2.1.2 Geology and Hydrology

The Chimacum Creek watershed is located on the northeast corner of the Olympic Peninsula, Washington, where two main forks (i.e., the main stem and east fork) flow north to the outlet in Port Townsend Bay. The 37 mi^2 watershed is low-lying, with elevations ranging from 0-924 feet (Figure 2). The underlying geology primarily consists of Vashon-age glacial sediments that were deposited and shaped into north-south trending ridges during the last glaciation, approximately 16000-19000 years before present (Simonds, Longpré, & Justin, 2004). Post-glacial surface features were formed by river processes and landslides, and lowland valley soils are primarily peat.

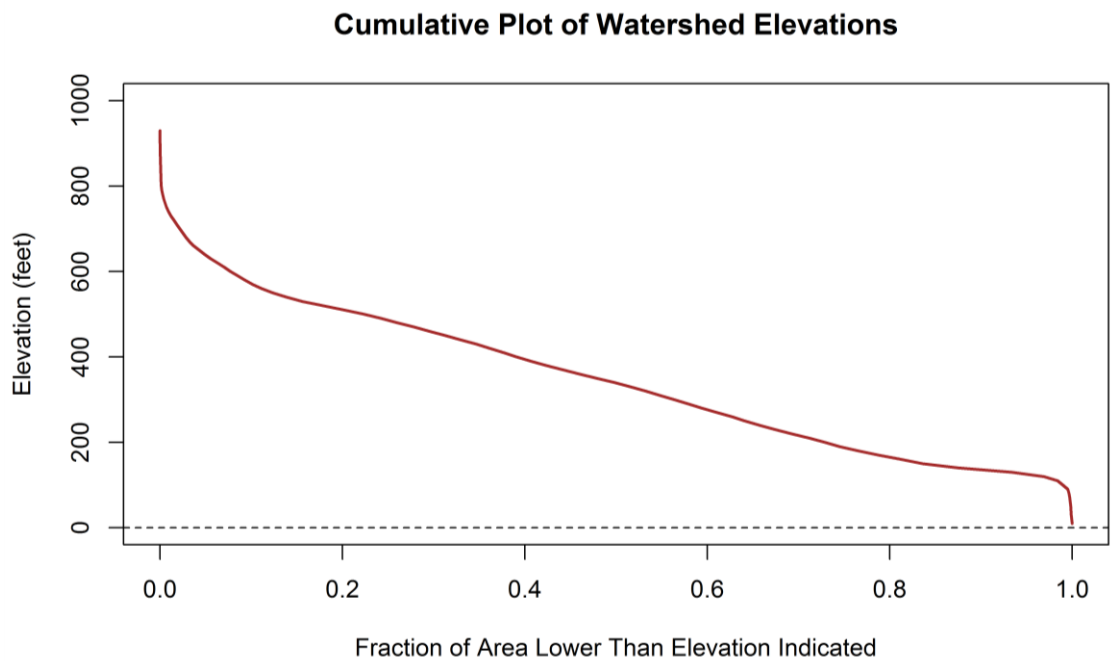


Figure 2. Hypsometric Curve showing cumulative elevation in the Chimacum Creek watershed; where the curve is flat, there is more area of the watershed in that elevation band.

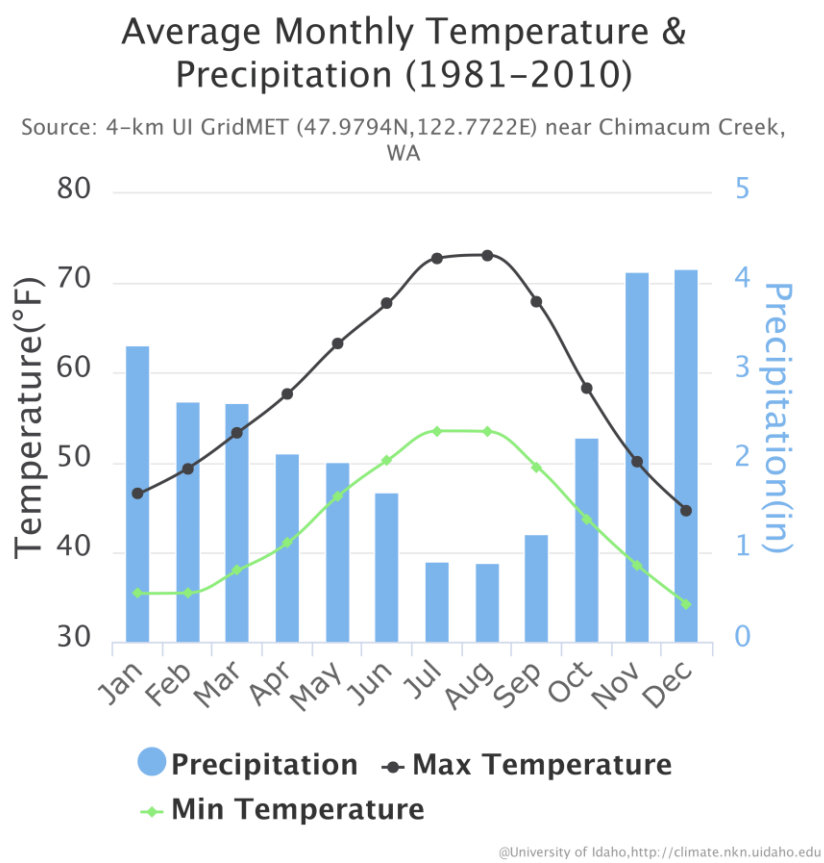


Figure 3. Average minimum and maximum monthly temperature (°F, shown as lines) and total monthly precipitation (inches, shown as bars) from 1981-2010 over Chimacum Creek, WA (Climate Impacts Research Consortium, 2016).

The watershed is in the rain shadow of the Olympic Mountains, and is subject to a maritime climate with relative high winter precipitation and low summer precipitation (Figure 3). Average total annual precipitation measured in at National Weather Service station Chimacum 4S, in Center, WA, is 30 inches (Gately et al., 2015). Precipitation generally falls only as rain in this low-lying watershed. Long-term average precipitation patterns indicate that precipitation rates are highest in the headwaters of the main stem (Map 4).

Streamflow data were collected from 1952-1958 by the USGS (Station 12051500) near RM 6.5, and from 2003-2016 by the Washington Department of Ecology at RM 0.1 (https://fortress.wa.gov/ecy/eap/flows/station.asp?wria=17#block2) (Map 4). The hydrograph generally follows a rain-dominated pattern with high flows during the wet (i.e., fall-spring) months, and low flows during the dry (i.e., summer) months. An investigation into surface water-ground water interactions in the Chimacum Creek watershed determined that the creek receives a net gain of 5-7 cubic feet per second (cfs) of streamflow from groundwater sources, but that the amount and direction of surface water-ground water interaction vary spatially (Simonds et al., 2004). The magnitude and timing of any irrigation withdrawals is not known. Note that modifications to the stream network have occurred, including re-routing of Swansonville Creek to flow north into the east fork, and of Delanty Lake to flow south into the main stem (Bahls & Rubin, 1996).

The magnitude and recurrence intervals of peak flows and low flows have been estimated in several ways, all of which are based on limited observational data (Table 2). (Smayda Environmental Associates, 2001) (their Table 3) presents peak flow statistics on the main stem at the decommissioned USGS gage at RM 6.5 on the main stem. They assessed a range of methods to predict peak flows based on statistical modeling methods, and presented a best estimate for the following flows: average annual flow of 10.6-13.7 cfs, bankfull flow of 63-86 cfs, the lowest seven-day average flow of 2.1 cfs and a 100-year flood magnitude of 753 cfs. Peak flows were measured at approximately RM 2.7 by Jefferson County Conservation District during 1998-2000 and peak maxima ranged from 125 to 250 cfs (Correa, 2002). Low flows were additionally monitored in 1999 and 2000, and lowest seven-day average flow were 4.2 cfs and 0.3 cfs respectively (Gately, G. 2001).

Table 2. Estimates for stream flow magnitudes of different recurrence intervals for 3 locations in the stream network. Q2 is the estimated streamflow discharge (in cubic feet per second, cfs) for a flow that has a 50% probability of occurring in any given year, which equates to a 2-year recurrence interval. Likewise, Q10, Q25, Q50, Q100, and Q500 are estimates for streamflow for a 10, 25, 50, 100, and 500-year recurrence interval. Note that these values are predicted from limited gage records and are subject to relatively high uncertainty.

LOCATION	METHOD	Q2	Q10	Q25	Q50	Q100	Q500	NOTES
East Fork 0.0	Regression (U.S. Geological Survey, 2012)	75.6	130	158	183	204	263	Does not include Swansonville Creek due to historic re-routing and subsequent issues with watershed delineation
CH 2.9 (just upstream of confluence)	Regression (U.S. Geological Survey, 2012)	264	454	551	638	712	914	
CH 6.5 (at decommissioned USGS gage)	Regression (U.S. Geological Survey, 2012)	184	318	387	450	502	647	
CH 6.5 (at decommissioned USGS gage)	Ratio Method comparing to Snow Creek	131 - 173			536-753	582-753		Presented in (Smayda Environmental Associates, 2001)

Future climate in the Chimacum Creek area is projected to be approximately 5 °F warmer, and total annual precipitation is projected to increase approximately 1" by the 2050s (Figure 4 , (Climate Impacts Research Consortium, 2016)). Projected changes vary seasonally, with an increase in precipitation of 1-2" in the fall and winter months, and a decrease of 0.5" in the summer months. For rain-dominated watersheds in western Washington, such as Chimacum Creek, these increases in winter precipitation and decreases in summer precipitation drive hydrologic projections of increasing peak flows, decreasing low flow magnitudes, and increasing water temperatures into the future (T. Beechie et al., 2012; Elsner et al., 2010).

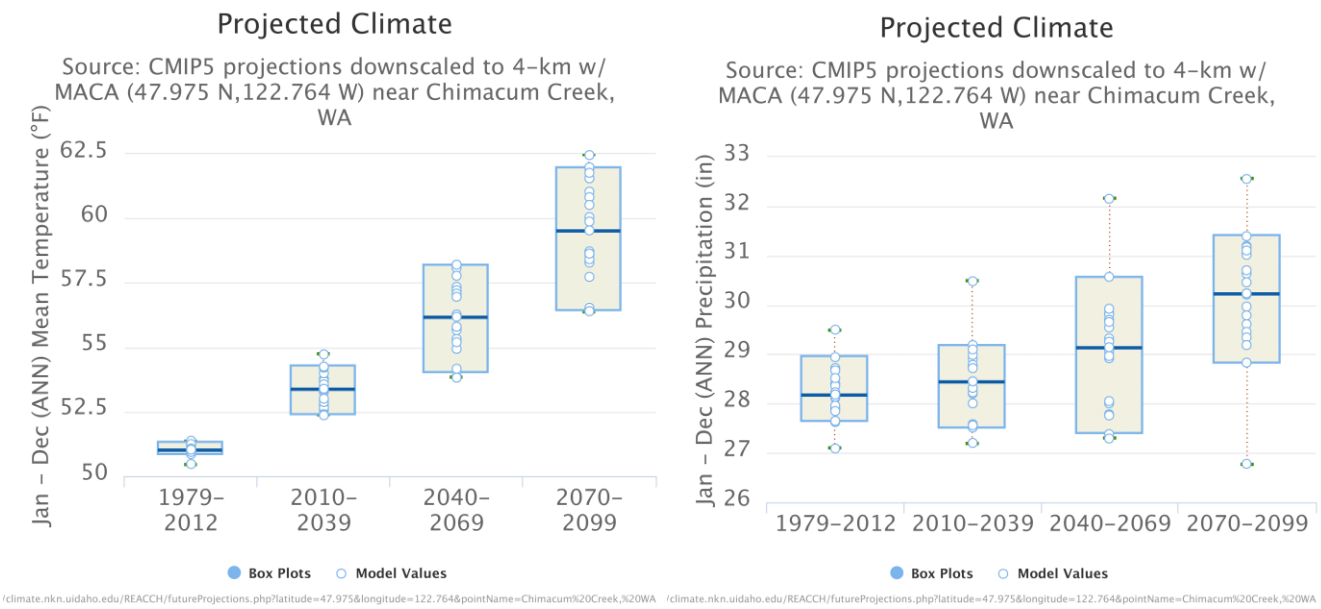


Figure 4. Boxplots of historical annual mean temperature (left) and total annual precipitation (right) compared to projections for three future periods. The distribution of values for each period and variable reflects output from 20 different global climate models, which were run with the RCP 8.5 emissions scenario, in a 2.5 x 2.5 mile domain over Chimacum Creek, WA (Climate Impacts Research Consortium, 2016).

2.1.3 Fish Habitat

The Coho population utilizes much of the Chimacum Creek stream network, from the outlet to approximately RM 12.4 at Old Eaglemount Road. Coho have been observed upstream of Old Eaglemount Road during very wet years, but the river typically goes dry during the summer and early fall months near RM 12.4 each year (personal communication with S. Doyle, 2016). Previous analyses have emphasized the importance of freshwater rearing habitat for Coho and suggested that rearing habitat and water temperature are key limiting factors (Bahls & Rubin, 1996; Correa, 2002). Observations of Coho at a nearby Intensively Monitored Watershed (IMW) indicate that peak Coho spawning extends from October-December and outmigration occurs from April-June; juveniles typically rear in freshwater for a year before outmigration (Table 3; Kinsel & Zimmerman (2011)).

Investigations in western Washington and Oregon determined that Coho abundance is highest in backwater pools in the summer and in beaver ponds in the winter, and further suggest that a lack of beaver ponds as the major limiting factor for Coho (Nickelson, Rodgers, Johnson, & Solazzi, 1992; Pollock, Pess, Beechie, & Montgomery, 2004). In addition to sparse beaver ponds and generally low frequency of pools and associated channel diversity, observations in Chimacum Creek suggest that pool sizes are generally smaller than the optimal pool size for summer rearing Coho (Bahls & Rubin, 1996).

Table 3. Illustration of the approximate timing of Coho life stages in Chimacum Creek, based on data from Big Beef Creek, Washington (Kinsel & Zimmerman, 2011) and personal communication with S. Doyle (2016).

LIFE STAGE	MONTH											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Juvenile Rearing												
Incubation												
Adult migration/ spawning												
Outmigration												

Summer chum utilize only the lowest section of Chimacum Creek from the outlet to RM 2, which has been the focus of conservation efforts. This analysis is focused on Chimacum Creek above the confluence of the main stem and the East Fork. However, restoration efforts focused on increasing the frequency of large wood in the channel and restoring natural riparian forest recruitment processes would likely improve fish habitat in the lower section of Chimacum Creek (personal communication with S. Doyle, 2016).

2.2 Findings

2.2.1 Geomorphology

Chimacum Creek is approximately 5-20 feet wide for most of its length, and is situated within a broad lowland valley. The width of the valley ranges from over 3000 feet wide to less than 100 feet; more constrained reaches are located where the creek cuts through glacial moraines, or where the creek descends from the upland glacial plateau to the lowland valley. Valley width is over 1000 feet on relatively flat portions of the upland glacial plateau, at elevations ranging from about 300-600 feet (see hypsometric curve in Figure 2).

We characterized the geomorphic features of the Chimacum Creek floodplain by mapping elevation of the valley relative to the elevation of the nearby water surface. This analysis utilizes a digital elevation mode derived from the 2005 lidar (Puget Sound Lidar Consortium, 2005) and stream location information from the National Hydrography dataset (USGS, 2016), which is manually revised based on 2015 NAIP aerial imagery (USDA, 2015). The digital elevation model is processed to de-trend the channel gradient and express the ground surface elevation of the valley bottom topography relative to the adjacent river channel using a Kernel Density method (Olsen, Legg, Abbe, & Radloff, 2014). The resultant surface is a Relative Elevation Model (REM), which highlights local variations in the floodplain surface. The REM map and elevation profiles across the channel and floodplain were then used to identify remnant floodplain features such as meander bends, and current impairments to floodplain connectivity such as channel down-cutting (i.e., incision).

The geomorphic features of the Chimacum Creek valley are consistent with its historic form as an alluvial valley with abundant wetlands (Mapbook 2). In particular, there are many continuous lowland areas surrounding what is now the channel (Figure 5). Most of these low areas identified in the REM maps also coincide with GLO survey wetland data presented in (Bahls & Rubin, 1996). We identified several locations where the channel is incised relative to its floodplain (Figure 6) and where the current channel is higher than nearby remnant meanders (Figure 7). Note that the topographic and REM analyses are limited by the spatial resolution and accuracy of the lidar data, and additional ground surveys are recommended (see Recommendations section).

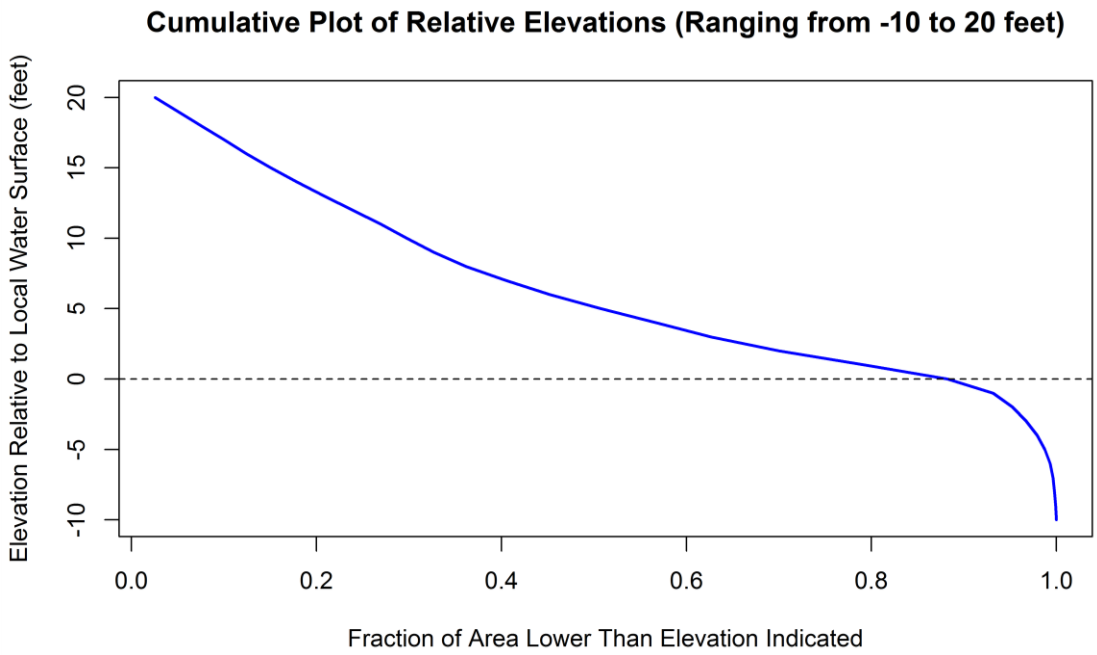


Figure 5. Hypsometric Curve showing cumulative elevation relative to water surface, for values that range from -10 feet below water surface to 20 feet above the local water surface in the Chimacum Creek watershed; note the substantial portion of valley area located below the local water surface (i.e. under the dashed line at 0 feet elevation).

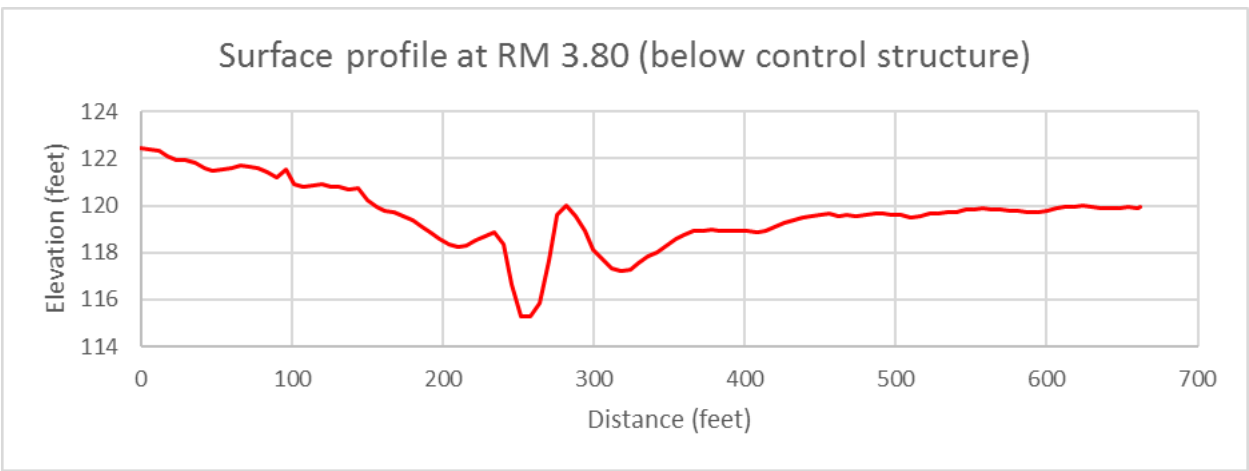


Figure 6. Elevation profile (looking downstream) across main stem Chimacum Creek at RM 3.8, illustrating channel incision (channel is located at approximately 250' across the transect) and relict meander bend (at approximately 310'). Note that profile is vertically exaggerated. See Figure 13 for location of transect.

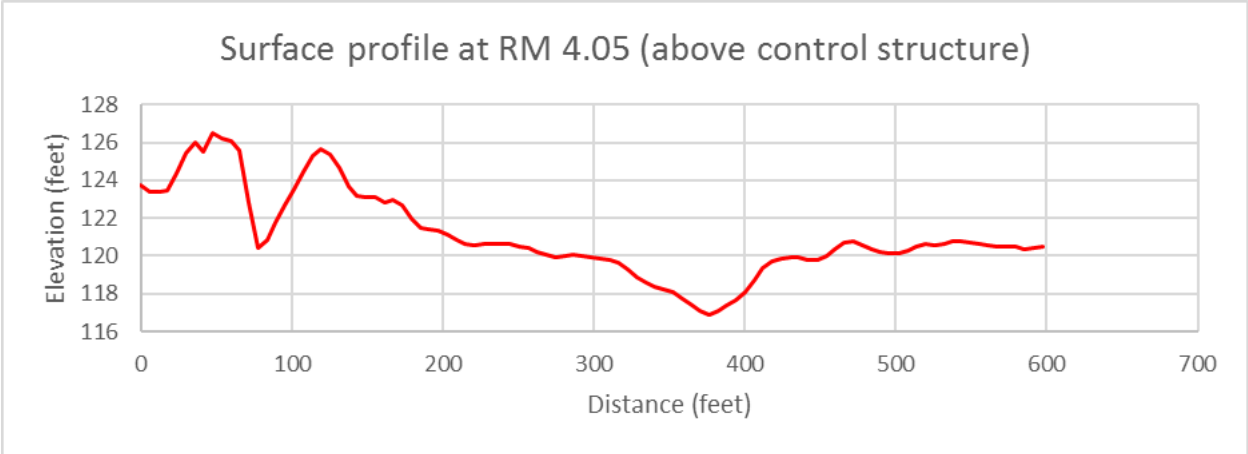


Figure 7. Elevation profile (looking downstream) across main stem Chimacum Creek at RM 4.05, illustrating elevation of channel (ditch, located at approximately 75' across the transect) relative to lower, relict meander bend evident in the REM map (at approximately 375' across the transect). Note that profile is vertically exaggerated. See Figure 13 for location of transect.

Geomorphic assessment in the 1990s found a general lack of large wood, channel complexity, and side channels (Map 3, data from Bahls & Rubin (1996)), and these features were reiterated in a 2002 assessment of habitat. The present assessment of channel and floodplain features based on the REM also found that channel complexity is low except where previous restoration actions such as channel re-meandering, have been implemented (Map 1).

2.2.2 Water Quality

The most frequent water quality exceedances for high temperature and low DO occurred in the main stem Chimacum Creek (Map 5). The spatial pattern of water quality exceedances overlaid with riparian vegetation suggests that locations downstream of unvegetated ditched sections are more likely to have impaired water quality, but there is not a robust statistical correlation (Gately et al., 2015). Water temperature is mainly controlled by net solar radiation and by advection of different temperature water from tributary inflow, or groundwater (Moore, Spittlehouse, & Story, 2006). Thus, in-situ heating in unvegetated reaches as well as warm inflow from unvegetated channel and tributary ditches are likely the main contributors. Spatial analysis of the aerial imagery indicates that approximately 44% of the main channel is unvegetated within the valley bottom (Table 1). Additionally, there are approximately 42 miles of ditches, of which only 31% is vegetated. It is unknown what percentage of the ditches are tributaries versus distributaries relative to the main channel.

Temperature exceedances are also associated with the flow regime in Chimacum Creek. Observational data collected by Jefferson County Conservation District suggest that water temperature is generally higher at lower streamflow values (Figure 8). The typical timing of low flows during the summer is coincident with warmer air temperatures, and, during low flows there is less cold water advected into the system and less total mass to heat. Shallow inundation of adjacent fields and subsequent warming and/or fertilizer contamination is also a possible contributing factor to water quality impairment. However, since inundation is more likely to occur during the cool, cloudy winter months, and since DO exceedances are correlated with temperature exceedances, this is likely a lesser contributor. Further assessment of contributing inflows during the low flow season are recommended (see Recommendations section).

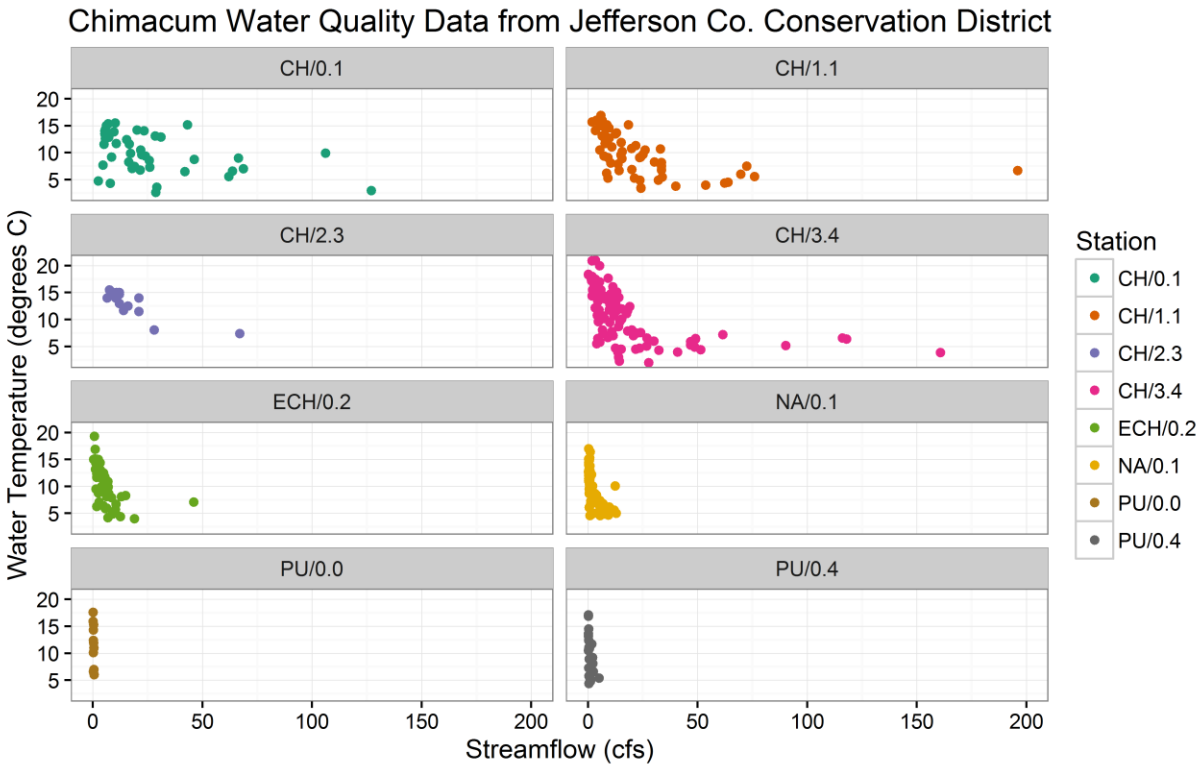


Figure 8. Water temperature as a function of observed streamflow for water quality sampling stations with flow data (Station names indicate the stream and the river mile, such that CH/0.1 is located on the main stem of Chimacum Creek at RM 0.1; CH = main stem Chimacum Creek, ECH = East Chimacum Creek, NA = Naylors Creek, PU = Putaansuu Creek). Data courtesy of Jefferson County Conservation District (Gately et al., 2015).

2.2.3 Riparian Vegetation

Valley reaches with riparian vegetation were delineated based on 2015 aerial imagery (USDA, 2015). We find that, within the valley bottom, approximately 56% of the main channel and 31% of the tributary/distributary ditches are vegetated. The riparian vegetation communities range in maturity and in areal extent, and are generally the result of restoration, such as planting of Conservation Reserve Enhancement Program (CREP) buffers (personal communication with Sarah Doyle, 2016). Over 9 river miles of riparian vegetation, covering over 80 acres, had been restored as of 2015 (Gately et al., 2015). Since the main land use of the valley area is agriculture or pasture, restored riparian vegetation is generally limited to an approximately 50-400-foot corridor immediately adjacent to the channel.

2.2.4 Beavers

Beaver dams are currently established in 17 locations within the valley bottom in both forks of the Chimacum River (personal communication with S. Doyle, 2016). Beavers serve an important function in the Chimacum River watershed, in that they create floodplain waterbodies and areas of backwater that create habitat complexity and are critical rearing areas for Coho (Pollock et al., 2004). However, beaver activity also leads to local flooding and felling of riparian trees, which can be problematic for landowners.

In an effort to support the Jefferson County Conservation District's beaver management plan, we assessed the watershed for suitability of beaver habitat. Beavers require robust riparian vegetation, and preferred

browsing species are cottonwood, willow, and aspen (Boyle & Owens, 2007). Due to concerns with beaver impact on maintaining immature riparian buffers when beavers are present, guidance from the Washington Department of Fish and Wildlife recommends interspersing less desirable riparian plant species Sitka spruce, elderberry, cascara, Indian plum, pacific ninebark, and twinberry with preferred browsing species (Washington Department of Fish and Wildlife, 2004).

Beavers also require perennial streamflow and relatively low stream power, which is controlled by channel gradient and streamflow. Previous investigations in the Pacific Northwest suggest a maximum gradient of 0.06 in the lower part of the watershed (where contributing area is higher), up to a maximum gradient of 0.1 in headwaters where contributing area is lower (see Figure 2 in (Pollock et al., 2004)). We extracted elevation data along the length of the main stem and East Fork to build a longitudinal profile of the river (i.e., channel elevation as a function of river mile). We then used the longitudinal profile to assess gradient along 0.2 mile sections of the river, except where there was a clear slope break.

The majority of the main stem and east fork of Chimacum Creek stream network are very low gradient (< 0.01) and stream power is sufficient low for beavers to establish (Map 5). Habitat limiting factors are therefore likely to be the presence of (1) sufficient riparian vegetation and (2) perennial streamflow. The main stem of Chimacum Creek near Old Eaglemount Road is known to become dry in the summer (Gately et al., 2015); perennial flow in other tributaries is not known. We delineated polygons of riparian vegetation in the watershed (based on 2015 aerial imagery from USDA (2015)), but an assessment of the maturity, abundance, and diversity of the vegetation would additionally support identification of suitable beaver habitat. Work by (Allen, 1983) suggests that beavers prefer smaller woody stems (i.e., 3-4 inches diameter), which implies that immature riparian vegetation may be more vulnerable to substantial impact from beaver activity.

2.2.5 Barriers to Fish Passage

Barriers to fish passage at road crossings in the Chimacum Creek watershed have previously been identified and prioritized for removal or modification (e.g., Bahls & Rubin, 1996; Correa, 2002; Smayda Environmental Associates, 2001). While fish passage assessment is outside the scope of this analysis, we emphasize that reconnection of viable habitat is high-priority (see Figure 9) restoration action to consider. As of 2001, the prioritized list of fish passage barriers on Chimacum Creek included the following (note that the number in parenthesis is priority level assigned in Table 2 of Till, Soncarty, & Barber, 2000):

- Chimacum Creek at Eaglemount Road (#5 for Jefferson County)
- Naylors Creek at West Valley Road (#9 for Jefferson County)
- Naylors Creek at Gibbs Lake Road (#11 for Jefferson County)
- Chimacum Creek at Center Road (#12 for Jefferson County)
- Chimacum Creek at Eaglemount Road (#26 for Jefferson County)
- E Chimacum Creek at Egg & I Road (#30 for Jefferson County)
- Unnamed Tributary to Chimacum Creek at Eaglemount Road (#40 for Jefferson County)
- Unnamed Tributary to Chimacum Creek at Center Road (#52 for Jefferson County)
- Unnamed Tributary to Chimacum Creek at Center Road (#82 for Jefferson County)

3. RECOMMENDATIONS

3.1 Goals

The main goals for recommended restoration actions in the Chimacum Creek watershed include:

- Increase availability of Coho rearing habitat, specifically floodplain water bodies and side channels
- Decrease water temperature (and therefore increase dissolved oxygen)
- Improve Coho rearing habitat in the main channel by increasing large wood and pool frequency
- Exclude invasive reed canary grass via shading by native trees and shrubs
- Address perennial inundation through land use planning

3.2 Restoration

3.2.1 Approach

Guidance for restoration strategies in the Pacific Northwest suggests a hierarchy of actions: (1) protecting high quality habitat, (2) reconnecting isolated habitat, (3) restoring natural hydrologic, riparian, and geologic processes and (4) improving instream habitat (T. J. Beechie et al., 2010; Roni et al., 2002). As such, we recommend applying a similar priority structure to the Chimacum Creek watershed (Figure 9). The approach and actions are further discussed below, with specific locations identified in Mapbooks 1 and 2, and in Appendix 1.

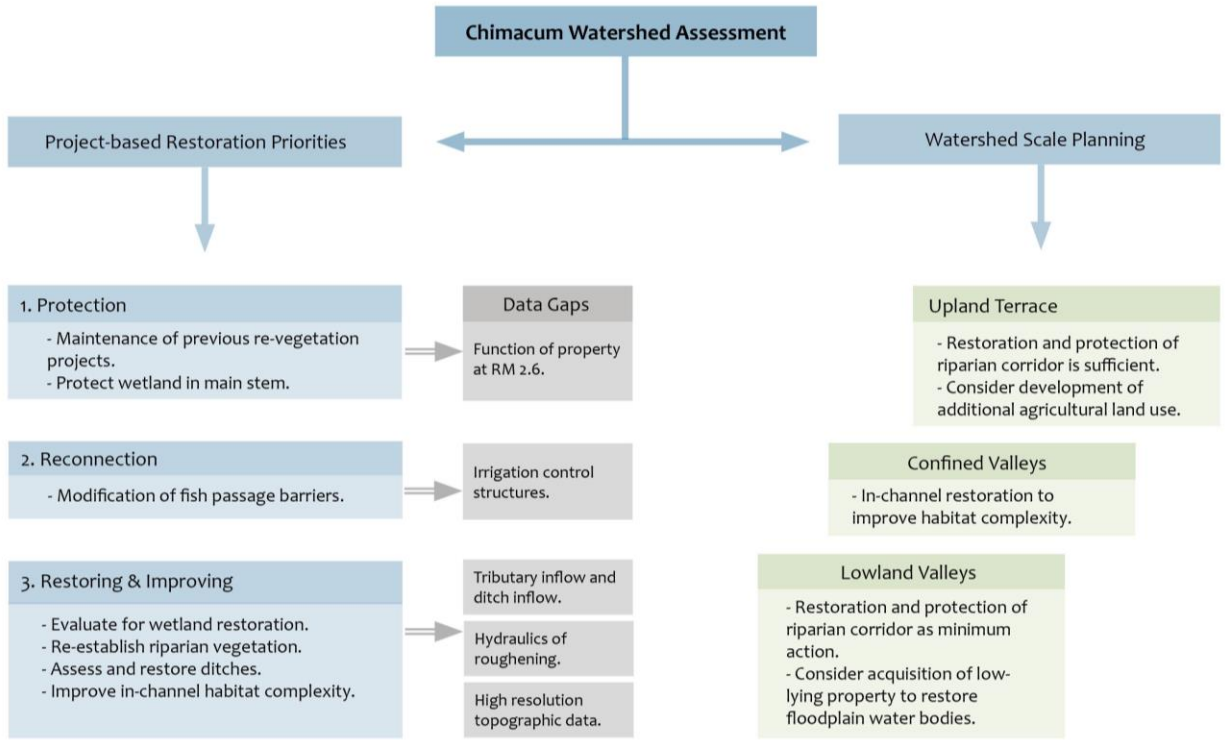


Figure 9. Conceptual diagram of restoration priorities.

The degradation of aquatic habitat in Chimacum Creek and frequent agricultural flooding are both primarily rooted in the conversion of a low-lying, wet alluvial valley to an agricultural valley. Based on review of previous reports and analysis of relict geomorphic features, Chimacum Creek historically consisted of complex channel forms with multiple meandering threads, as well as areas of connected wetlands that lacked channel form. These wetlands were particularly important for supporting Coho (Pollock et al., 2004).

A return to the historic state is undesirable because of the cultural and economic importance of agriculture to the valley and to the surrounding communities. However, restoration actions to protect and re-establish floodplain waterbodies, increase habitat connectivity, create channel complexity, and establish robust riparian vegetation are likely to have the most benefit for both fish habitat and water quality in the watershed. In this approach, we recommend the following prioritized actions:

1. Protect restoration investments by maintaining previous re-vegetation efforts, and protect functioning wetlands from land-use change,
2. Continue actions to remove and/or replace barriers to fish passage,
3. A suite of project-based actions to restore hydrologic, geomorphic, and riparian processes and improve habitat, including:
    a. Evaluating some properties for floodplain reconnection and wetland restoration over large areas;
    b. Re-establishing riparian vegetation over as much of the length of the main channel as possible;
    c. Assessing the quantity and quality of inflow from tributaries and tributary ditches, and re-establishing riparian vegetation or consolidating ditches where possible; and
    d. Creating in-channel habitat complexity by placing large wood. And,
4. Addressing key data gaps.

The recommended restoration actions presented in Appendix 1 include a qualitative assessment of restoration priority, based on the above list and analysis of the watershed. In particular, our findings suggest that the best opportunities to improve Coho habitat in the watersheds are (1) addressing high water temperatures through establishing riparian vegetation along the channel and ditches, and (2) re-establishing water bodies or complex channel forms in topographic low areas that were historically wetlands. We additionally suggest that locations in main stem Chimacum Creek are higher priority for restoration than east fork Chimacum Creek because water quality is relatively good in the east fork. However, the east fork has two long reaches with little habitat complexity (RM 2-3 and RM 3.5-5.0). One or two strategically located restoration projects to improve habitat complexity in these reaches could have large benefits for habitat connectivity in the east fork.

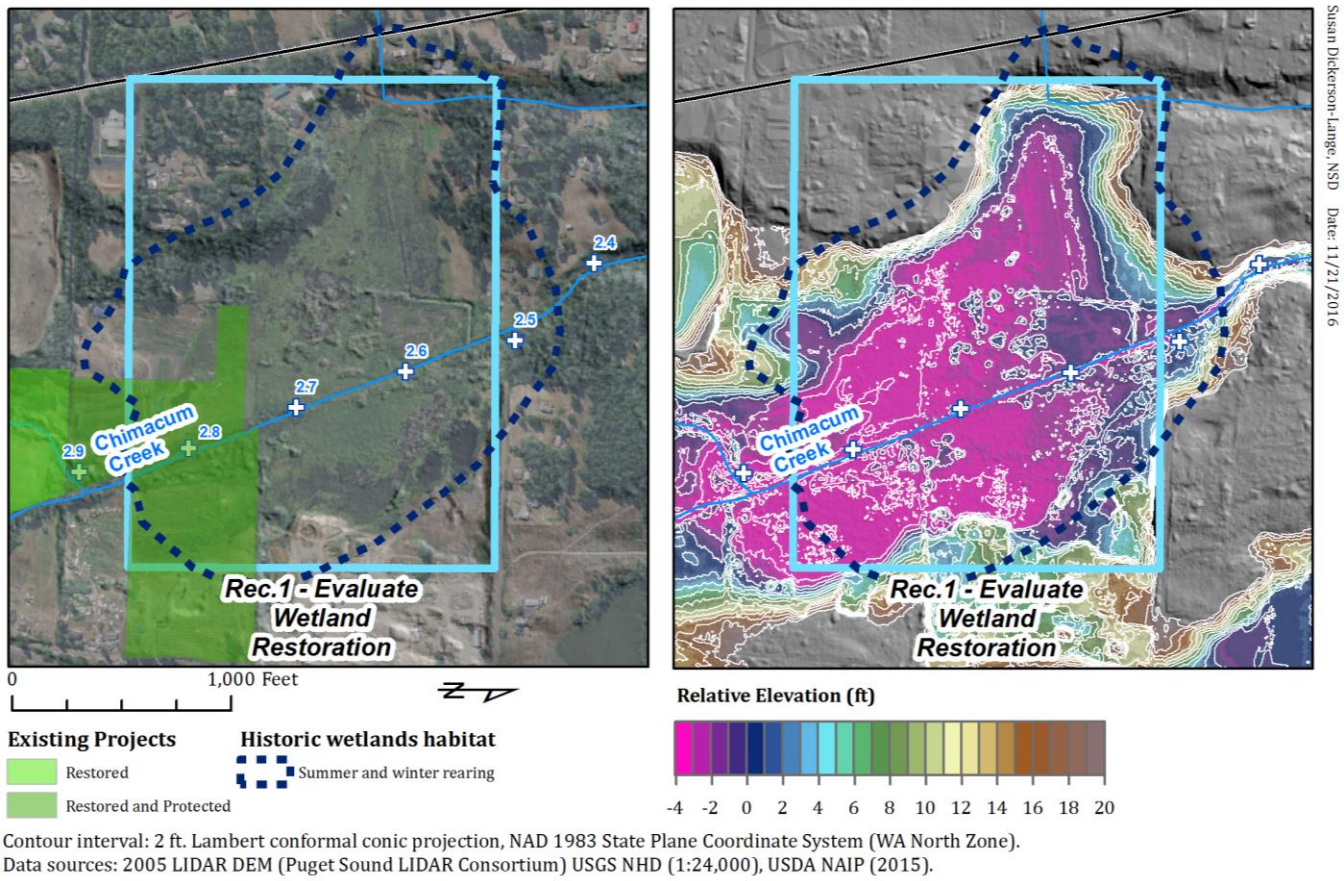
Since the natural function of Chimacum Creek relies upon large floodplain waterbodies, beaver activity, and riparian forests, there is high potential for land-use conflict when considering process-based restoration in concert with agricultural and residential land uses. We therefore recommend additionally considering watershed-scale planning to accommodate room for Chimacum Creek to function naturally where feasible and simultaneously designate locations for optimal agricultural land-use.

3.2.2 Protection

Protection of high-functioning habitat and previously restored areas is high priority. In particular, we recommend protecting established riparian vegetation communities, and maintaining locations that have been re-vegetated but where the riparian vegetation community is not yet fully established. Similarly, where

restoration actions have included the placement of large wood in the channel (e.g., near RM 10.3), we recommend re-planting the riparian forest in order to support continuing wood recruitment.

We additionally identified one location (RM 2.6) downstream of the confluence that appears from aerial imagery to be undeveloped wetland. However, zoning records indicate a mix of zoning for residential houses, agricultural open space and vacant land. We recommend an investigation of the zoning and ownership status of this land and possible protection as designated wetland.



Contour interval: 2 ft. Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA North Zone).
Data sources: 2005 LIDAR DEM (Puget Sound LIDAR Consortium) USGS NHD (1:24,000), USDA NAIP (2015).

Figure 10. Location near RM 2.6 where we recommend assessment of river and wetland function and zoning, for possible protection.

3.2.3 Reconnection

The reconnection of habitat via removal or modification of fish passage barriers is largely being actively addressed in the watershed (Gately et al., 2015; Smayda Environmental Associates, 2001). In addition to continuing these efforts, we identified the operation of an irrigation control structure at approximately RM 4.0 as a critical data gap (Figure 11). The operation of this structure is unknow, but if and when the gate is closed the structure may impede passage and affect downstream flow magnitudes. Low flow is a possible contributor to water quality exceedances, and blocking passage during the warmer summer months can also impede access to upstream or downstream thermal refugia (Torgersen, Ebersole, & Keenan, 2012).

Figure 11. Field photograph of irrigation control structure near RM 4.0, facing left bank.

3.2.4 Restoring and Improving

We recommend a suite of project-based actions to specifically address the loss of habitat, impaired water quality, and agricultural flooding in ways that are compatible with the geomorphic characteristics of the valley.

Evaluate Potential for Wetland Restoration

By restoring historic wetlands to some locations, rearing habitat for Coho is vastly improved and water temperature is lowered through shading from wetland plant communities and ground water-surface water exchange. Off-channel water storage is increased, which may reduce inundation in downstream locations (Watson, Ricketts, Galford, Polasky, & O'Niel-Dunne, 2016). The locations which are identified in Appendix 1 and Mapbooks 1 and 2 for wetland restoration coincide with historic wetlands and topographically low areas in the floodplain. These locations are additionally ideal to support and encourage beaver activity through establishing appropriate vegetation.

This restoration strategy is only feasible where property can be acquired for restoration over most or all of it. Wetland restoration projects will likely include some amount of excavation to reconnect the channelized creek with topographically low areas. Establishment of the wetland vegetation community would require planting of native trees and shrubs in combination with repeat treatment to suppress reed canary grass during the first few years while the native plants establish. Two-dimensional hydraulic modeling and some hydrology modeling are recommended to assess potential for re-engagement and to direct restoration design.

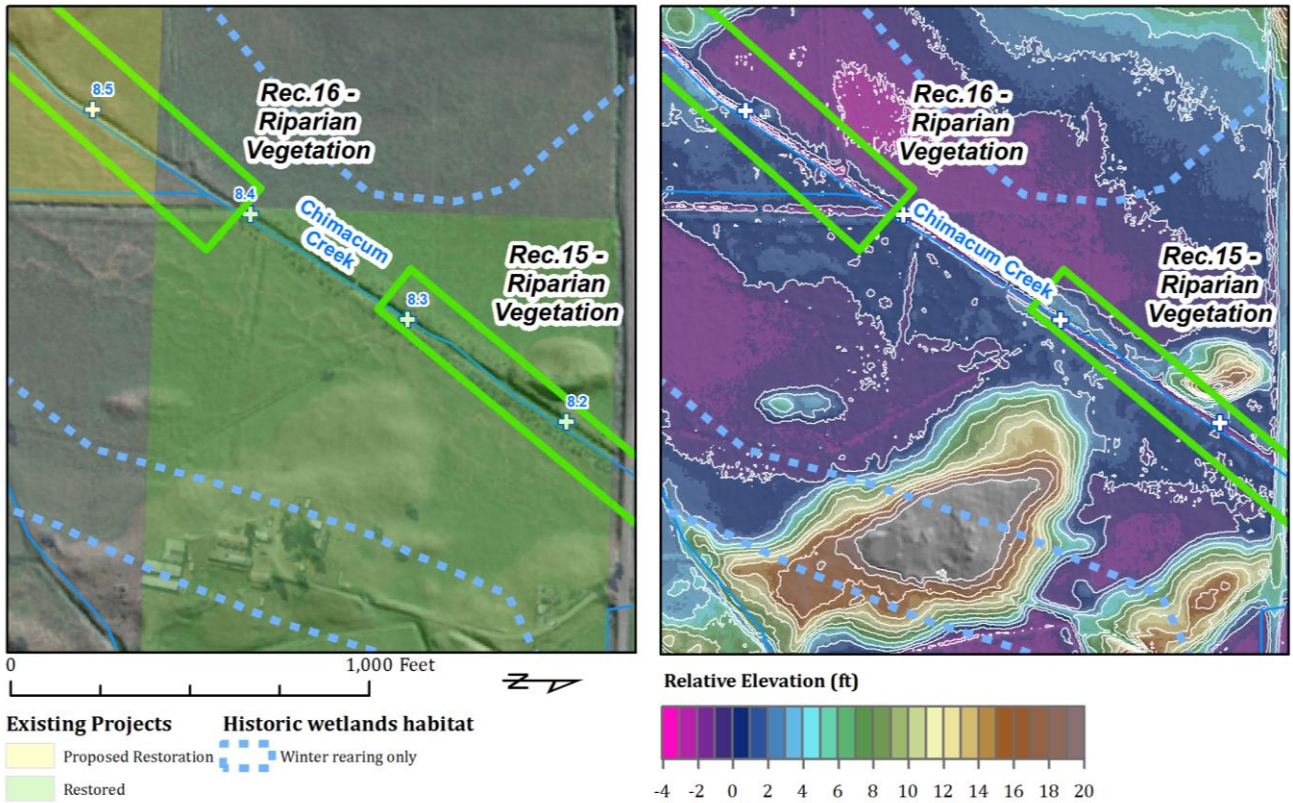
Re-establish Riparian Vegetation

Riparian vegetation is a primary control on stream temperature because mature riparian vegetation shades to the creek, reduces water temperatures, and ultimately excludes invasive reed canary grass. Re-establishment of riparian vegetation should be considered a minimum restoration action to improve water quality and aquatic habitat across the Chimacum Creek valley (Figure 12). Riparian vegetation provides long-term habitat benefits, by ultimately providing a source of large wood to the creek and by supporting beavers that create additional fish habitat. Specific locations for re-vegetation are recommended based on vegetation mapping from 2015 aerial photographs (USDA, 2015).

The EPA guidelines require 100 foot buffers on each side of the stream. In a review of relevant literature, Broadmeadow & Nisbet (2004) report effective buffer widths that range from approximately 45 – 220 feet to meet temperature moderation goals. Based on the width of Chimacum Creek in a relatively flat valley, the effective buffer width for shading is likely to be on the lower end of the range. However, wider buffers are likely needed to support beavers.

Assess and Restore Unvegetated Tributary Ditches

We identified approximately 28 miles of unvegetated ditches in the Chimacum Creek stream network from analysis of aerial imagery (USDA, 2015). The flow direction (tributary versus distributary) and approximate magnitudes of these ditches represent a major data gap. Where unvegetated ditches are acting as tributaries, they may be contributing to impaired water quality by conveying high temperature water that has been heated by direct sunlight. Conversely, distributary channels may be lowering flow in the main channel and additionally contributing to high water temperatures (Figure 8). We recommend that the network of ditches be mapped and assessed for water quality, flow direction, and flow magnitude. At a minimum, riparian buffers should be established along these tributaries, and possibilities for tributary ditch consolidation should be assessed (Figure 12).



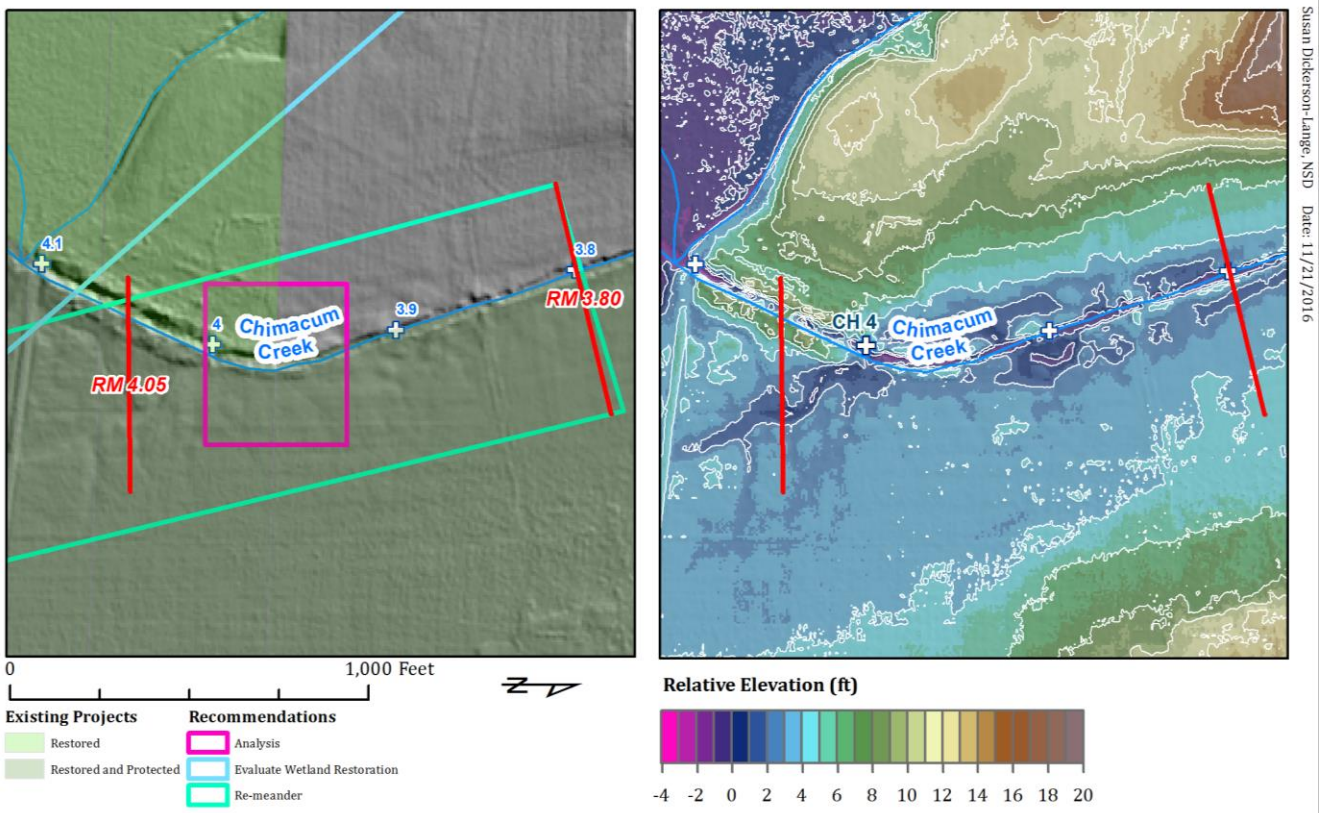
Contour interval: 2 ft. Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA North Zone).
Data sources: 2005 LIDAR DEM (Puget Sound LIDAR Consortium) USGS NHD (1:24,000), USDA NAIP (2015).

Susan Dickerson-Lange, NSD Date: 11/21/2016

Figure 12. Hillshade map (left) and relative elevation map (right) for location near RM 8.2-8.3 where we recommend establishing (Rec. 16) or protecting (Rec. 15) riparian buffers. Additionally, note the unvegetated ditch that joins Chimacum Creek at RM 8.4; we recommend hydrologic assessment of the ditch network and establish of riparian buffers around tributary ditches that contribute substantial inflow.

Improve In-Channel Habitat Complexity

In-channel habitat complexity can be improved where the channel is hydrologically disconnected from its floodplain as a result of incision (i.e., downcutting) or ditching. Analysis of relict floodplain features and topographic profiles across more confined reaches were used to identify several locations with opportunities to improve habitat complexity. At all locations, placement of large wood structures will create additional pools and in-stream shelter for fish. Additionally, where the channel is incised the re-introduction of large wood to the channel can trap sediment and raise bed elevation, and raise water surface elevation, thereby re-engaging the floodplain and connecting the channel to relict side channels (Figure 13). In locations with deeper incision, channel re-meandering and/or excavation of an inset floodplain may also be an option for creating side channels. This restoration strategy is appropriate in reaches with relict channel features and room for channel migration and side channel engagement to occur. Topographic survey and 2-dimensional hydraulic modeling are recommended to assess potential for re-engagement and to guide restoration design.



Contour interval: 2 ft. Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA North Zone).
Data sources: 2005 LIDAR DEM (Puget Sound LIDAR Consortium) USGS NHD (1:24,000), USDA NAIP (2015).

Figure 13. Hillshade map (left) and relative elevation map (right) of location near RM 3.8-4.1 where we recommend analysis related to the operation of a control structure located near RM 4.0, and possible restoration to improve channel complexity. Elevation profiles for the two transects indicated as red lines, are shown in Figures 6 and 7.

3.2.5 Watershed-Scale Planning

From the perspective of watershed-scale planning, the priority becomes balancing the economic viability of the valley with providing as much room as possible for river processes to function naturally. Widespread restoration and land protection can be perceived as encroaching upon agriculture; however, based on the topography and hydrology of the floodplain, many locations we identify for possible restoration are likely to already experience high groundwater levels or shallow inundation that hinder productive agriculture.

We recommend considering watershed-planning based on the following geomorphic units:

- Lowland alluvial valley - low areas of the valley that were perennially inundated historically are high priority for restoration and are likely present major drainage challenges for agriculture. Where possible, agriculture should be concentrated in higher portions of the valley (see Mapbook 2). During a field visit, we observed houses and barns located at the top of hummocks, indicating that adapting land use to higher relative elevations is not inconsistent with current practices.
- Confined valley - locations where the creek flows through glacial moraines, which consist of sediments deposited during the last glaciation, are 'pinch points' in the valley and the gradient of the creek is steeper. Similarly, gradient is higher where the creek descends from the upland glacial terrace to the lowland valley. These locations are generally compatible for restoration along with

agricultural or residential land use because river processes are more contained in the valley. However, the creek is also likely to be incised (i.e., down-cut) in these locations and restoration may increase overbank flooding.

- Upland terraces – the relatively flat upland glacial terraces in the Chimacum Creek watershed results in alluvial valleys high in the system (e.g., near Delanty Lake). Restoration to protect and improve water quality (i.e., riparian vegetation) is important in these locations, but there may also be opportunities to expand agricultural land use. In particular, both the USDA prime farmland soil classification data (Map 7) and surface slope (Map 8) suggest that upland agriculture may be feasible, given water sources and additional soils assessment. Substantial portions of the upland glacial terraces are relatively flat, with slopes of 0-5%, and soils have been mapped as potential farmland. A pilot project to explore land-use development in the upland alluvial valleys could make a competitive proposal for a program like Floodplains by Design (http://www.floodplainsbydesign.org/).

3.2.6 Data Gaps and Future Analyses

Several data gaps were identified in the analysis, and some are briefly discussed above. The compilation of data gaps is presented here in approximate priority order:

- Approximately 42 miles of ditches, of which 31% is vegetated, leaving 28 miles of unvegetated ditches in the network. Flow direction (tributary versus distributary) and approximate magnitudes need to be established in order to prioritize areas for re-vegetation and/or consolidation. The location and function of agricultural drainage tiles also represents a data gap for the quality and quantity of inflows.
- An irrigation control structure was observed at RM 4.0. The operation of this structure represents a major data gap because of the hydraulic control that impoundment of flow exerts of the river. We hypothesize that channel incision surrounding this structure is related to its presence and operation, but the timing and nature of its operation are unknown. Additionally, any other control structures in the valley and their operations should be identified if possible.
- Streamflow has been observed over approximately 12 years near the outlet of Chimacum Creek, but discharge in either fork or in major tributaries represents a data gap.
- The 2005 lidar is relatively low resolution compared to recent standards. The morphology of the digital elevation model suggests that returns from reed canary grass in the channel and riparian vegetation were included as bare earth returns in some locations. Improved lidar would contribute to improved geomorphic assessment, and provide based data for restoration design and hydraulic modeling.
- Restoration of riparian vegetation should reflect the optimal community for restored conditions. Whereas much is known about native plant communities in general, a site-specific assessment of optimal vegetation community for the geomorphic and hydrologic conditions would support efforts to develop robust riparian vegetation and shade out reed canary grass.

In addition, the following future analyses are recommended:

- 2-Dimensional hydraulic modeling is recommended for any location in which roughness will be added to the channel (i.e., large wood placements) or where floodplain features will be re-engaged. Hydraulic modeling allows for quantitative prediction of flows at which floodplain features will connect with the main channel, and for assessment of overbank flood elevations adjacent to and upstream of restoration actions.

- Additional hydrologic information is needed and could be obtained through flow monitoring, rainfall-runoff modeling, or a combination thereof. Additionally, an investigation of agricultural or residential surface water inflows and withdrawals is recommended.
- Assessment of the physical feasibility of further agricultural development on high ground would support watershed-scale planning efforts. This assessment should include evaluation of soils and availability of groundwater or surface water for irrigation.

4. REFERENCES

Allen, A. W. (1983). *Habitat Suitability Index Models: Beaver*. Fort Collins, CO. Retrieved from http://breb.ro/Publicatii/hab_suitability_index_models_beaver.pdf

Bahls, P., & Rubin, J. (1996). *Chimacum watershed coho salmon habitat restoration assessment*. Kingston, WA.

Beechie, T., Imaki, H., Greene, J., Wade, A., Wu, H., Pess, G., … Mantua, N. (2012). RESTORING SALMON HABITAT FOR A CHANGING CLIMATE. *River Research and Applications*, *22*(July 2011), n/a–n/a. http://doi.org/10.1002/rra.2590

Beechie, T. J., Sear, D. a., Olden, J. D., Pess, G. R., Buffington, J. M., Moir, H., … Pollock, M. M. (2010). Process-based Principles for Restoring River Ecosystems. *BioScience*, *60*(3), 209–222. http://doi.org/10.1525/bio.2010.60.3.7

Boyle, S., & Owens, S. (2007). *North American Beaver (Castor Canadensis): A Technical Conservation Assessment. Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project*. Retrieved from http://www.fs.fed.us/r2/ projects/scp/assessments/northamericanbeaver.pdf

Broadmeadow, S., & Nisbet, T. R. (2004). The effects of riparian forest management on the freshwater environment: a literature review of best management practice. *Hydrology and Earth System Sciences Discussions*, *8*(3), 286–305. http://doi.org/10.5194/hess-8-286-2004

Climate Impacts Research Consortium. (2016). Northwest Climate Toolbox. Retrieved from http://nwclimatetoolbox.weebly.com/dashboard.html

Correa, G. (2002). *Salmon and Steelhead Habitat Limiting Factors, Water Resource Inventory Area 17, Quilcene/Snow Basin: Final Report*.

Elsner, M. M., Cuo, L., Voisin, N., Deems, J. S., Hamlet, A. F., Vano, J. A., … Lettenmaier, D. P. (2010). Implications of 21st century climate change for the hydrology of Washington State. *Climatic Change*, *102*(1-2), 225–260. http://doi.org/10.1007/s10584-010-9855-0

Gately, G., Clarke, J., Ecelberger, D., & Schrader, C. (2015). *Chimacum Watershed Water Quality and Fishes: A Comprehensive Review*. Olympia, WA. Retrieved from http://www.jeffersoncd.org/wp-content/uploads/2015/05/Chimacum-Report-with-appendices_4-24-15.pdf

Homer, C. G., Dewitz, J. A., Yang, L., Jin, S., Danielson, P., Xian, G., … Megown, K. (2015). Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing*, *81*(5), 345–354. http://doi.org/10.14358/PERS.81.5.345

Kinsel, C., & Zimmerman, M. (2011). *Intensively Monitored Watersheds: 2009 Fish Populations Studies in the Hood Canal Stream Complex*. Olympia, WA. Retrieved from http://wdfw.wa.gov/publications/01221/wdfw01221.pdf

Moore, R. D., Spittlehouse, D. L., & Story, A. (2006). Riparian microclimate and stream temperature response to forest harvesting: A review. *Journal Of The American Water Resources Association*, *7*(4), 813–834. http://doi.org/10.1111/j.1752-1688.2005.tb04465.x

Nickelson, T. E., Rodgers, J. D., Johnson, S. L., & Solazzi, M. F. (1992). Seasonal changes in habitat use by

juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. *Canadian Journal Of Fisheries And Aquatic Sciences*, 49(4), 783–789.

Olsen, P. L., Legg, N. T., Abbe, T. B., & Radloff, J. K. (2014). *A Methodology for Delineating Planning-Level Channel Migration Zones*. Retrieved from https://fortress.wa.gov/ecy/publications/SummaryPages/1406025.html

Pollock, M. M., Pess, G. R., Beechie, T. J., & Montgomery, D. R. (2004). The importance of beaver ponds to coho salmon production in the Stillaguamish River Basin, Washington, USA. *North American Journal of Fisheries Management*, 24(October 2015), 749–760. http://doi.org/10.1577/M03-156.1

PRISM Climate Group. (2012). PRISM Climate Group. Retrieved from http://prism.oregonstate.edu

Puget Sound Lidar Consortium. (2005). Olympic Peninsula Acquistion. Retrieved from www.pugetsoundlidar.org

Roni, P., Beechie, T. J., Bilby, R. E., Leonetti, F. E., Pollock, M. M., & Pess, G. R. (2002). A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds. *North American Journal of Fisheries Management*, 22(1), 1–20. http://doi.org/10.1577/1548-8675(2002)022<0001:AROSRT>2.0.CO;2

Simonds, F. W., Longpré, C. I., & Justin, G. B. (2004). *Ground-Water System in the Chimacum Creek Basin and Surface Water/Ground Water Interaction in Chimacum and Tarboo Creeks and the Big and Little Quilcene Rivers, Eastern Jefferson County, Washington*. Reston, Virginia.

Smayda Environmental Associates. (2001). *West Fork Chimacum Creek near RM 6: Design Report for replacing an undersized box culvert and restoring 2200 feet of stream and buffer to improve salmon habitat*.

Till, L., Soncarty, C., & Barber, M. (2000). *Jefferson County Barrier Culvert Inventory and Prioritization - Final Report*. Olympia, WA. Retrieved from http://wdfw.wa.gov/publications/00587/wdfw00587.pdf

Torgersen, C., Ebersole, J., & Keenan, D. (2012). *Primer for identifying cold-water refuges to protect and restore thermal diversity in riverine landscapes. EPA scientific guidance handbook*. Seattle, WA. http://doi.org/EPA 910-c-12-001

U.S. Geological Survey. (2012). The StreamStats program. Retrieved from http://streamstats.usgs.gov

USDA. (2015). NAIP Imagery. Retrieved from https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

USGS. (2016). National Hydrography Dataset. Retrieved from http://nhd.usgs.gov/

Washington Department of Fish and Wildlife. (2004). *Living with Beavers – Adapted from "Living with Wildlife in the Pacific Northwest*. Olympia, WA. Retrieved from http://scc.wa.gov/wp-content/uploads/2015/06/LivingWithBeavers_WDFW_2004.pdf

Watson, K. B., Ricketts, T., Galford, G., Polasky, S., & O'Niel-Dunne, J. (2016). Quantifying flood mitigation services: The economic value of Otter Creek wetlands and floodplains to Middlebury, VT. *Ecological Economics*, 130, 16–24. http://doi.org/10.1016/j.ecolecon.2016.05.015

Appendix 1

Site-Specific Recommendations

Natural Systems Design

THIS PAGE INTENTIONALLY LEFT BLANK

Table 1. Site specific recommendations.

REC #	TYPE	RM	LOCATION	RECOMMENDATION CATEGORY	RECOMMENDATION	PRIORITY	CONSIDERATIONS
1	Protection and Restoration	2.6	Main stem, downstream of confluence	Protect Current Land Use; Evaluate Potential for Wetland Restoration	Existing wetland currently zoned as mix of rural residential, agricultural open space, and vacant land. 2015 aerial photo shows development only at outer edges. Protect from additional development and evaluate for wetland restoration.	High	Additional opportunities here to improve channel/habitat complexity.
2	Restoration	3.3	Main stem, upstream of confluence	Roughen	Roughen channel with large wood to create habitat diversity.	Low	Riparian vegetation is mature, and 1996 data indicates presence of Coho and gravel, but no large wood, near RM 3.2. Additionally recommend 2-D hydraulic modeling to assess activation flows and changes in inundation from roughening, particularly since there are houses nearby.
3	Data Gap	3.2	Right bank tributary (ditch) to main stem	Analysis	Evaluate flow direction, discharge, and water quality in the ditch.	High	Two monitoring locations observed temperature exceedances 0.3 miles downstream of this tributary-ditch.
4	Restoration	3.9-4.1	Main stem	Re-meander	Re-meander small bends and roughen channel to aggrade incised channel downstream of control structure. Consider re-connecting to larger right bank meander upstream of control structure.	Medium	Good opportunities to add in-channel habitat complexity here, but restoration at this location depends on future actions regarding irrigation control structure. At a minimum, consider riparian planting on unvegetated left bank. Additionally recommend 2-D hydraulic modeling to assess activation flows and changes in inundation from roughening.
5	Data Gap	4	Main stem	Analysis	Investigate operation of irrigation control structure to determine effects on upstream flooding and downstream incision.	High	

REC #	TYPE	RM	LOCATION	RECOMMENDATION CATEGORY	RECOMMENDATION	PRIORITY	CONSIDERATIONS
6	Restoration	4.1 - 4.2	Main stem	Evaluate Potential for Wetland Restoration	Evaluate potential for wetland restoration in site of historic perennial wetland.	High	Alternatively, maintain and re-establish riparian vegetation. Investigate amount and timing of tributary-ditch inflows and consider planting riparian vegetation along ditches.
7	Restoration	4.3-4.5	Main stem	Riparian Vegetation	Establish riparian vegetation along ditched reach.	High	Water quality exceedances in this reach
8	Restoration	5.1-5.4	Main stem, upstream of glacial moraine	Evaluate Potential for Wetland Restoration	Evaluate potential for wetland restoration in site of historic perennial wetland.	High	Alternatively, establish riparian vegetation (see Recommendation #9).
9	Restoration	5.0-6.1	Main stem	Riparian Vegetation	Establish riparian vegetation along ditched reach.	High	
10	Restoration	5.7-6.1	Main stem	Evaluate Potential for Wetland Restoration	Evaluate potential for wetland restoration in site of historic perennial wetland.	Medium	Appears to be ponds in the 2015 aerial photograph.
11	Data Gap	7.3	Right bank tributary-ditch to main stem	Analysis	Investigate inflow from unvegetated tributary ditch.	High	The 1996 data identifies a small pool in this tributary-ditch, but no Coho or wood.
12	Restoration	7.1-7.3	Main stem, confined reach	Roughen	Roughen channel with large wood to create habitat diversity.	Low	The 1996 data identifies some wood, pools, and Coho in this reach. Could be opportunity to enhance habitat further by placing large wood. Additionally recommend 2-D hydraulic modeling to assess activation flows and changes in inundation from roughening.
13	Restoration	7.4-7.7	Main stem	Evaluate Potential for Wetland Restoration	Evaluate potential for wetland restoration in site of historic perennial wetland.	High	Could also re-meander for smaller footprint, some evidence of relict meander features. At a minimum, establish riparian vegetation (see Recommendation #14).

REC #	TYPE	RM	LOCATION	RECOMMENDATION CATEGORY	RECOMMENDATION	PRIORITY	CONSIDERATIONS
14	Restoration	7.4-7.8	Main stem	Riparian Vegetation	Establish riparian vegetation along ditched reach.	High	
15	Protection	7.9-8.3	Main Stem	Riparian Vegetation	Protect and enhance riparian vegetation planted during previous restoration efforts; 2015 imagery suggests very small plants.	High	Note that there are existing beaver dams, and the low lying portion of the valley adjacent to the right bank could possibly become inundated.
16	Restoration	8.4-8.8	Main Stem	Riparian Vegetation	Establish riparian vegetation along ditched reach.	High	
17	Restoration	8.6-8.9	Main Stem	Re-meander	Re-meander and/or roughen channel in this reach through wood placement; some suggestion of relict channel features from the REM map.	Low	Additionally recommend 2-D hydraulic modeling to assess activation flows and changes in inundation from roughening.
18	Data Gap	8.8	West Valley tributary-ditch and unnamed tributary-ditch at left bank	Analysis	Investigate inflow from unvegetated west valley tributary ditch and from partially vegetated unnamed tributary ditch.	High	Water quality exceedances in both tributary ditches; establish or enhance riparian vegetation along ditches if inflow is substantial.
19	Restoration	9.0-9.4	Main stem, confined reach	Roughen	Improve habitat complexity by adding roughness; opportunity to re-engage flood plain.	Low-Medium	Additionally recommend 2-D hydraulic modeling to assess activation flows and changes in inundation from roughening.
20	Restoration		Barnhouse Creek	Riparian Vegetation	Establish riparian vegetation along ditched reach.	High	Water quality exceedances at confluence of Barnhouse Creek and Chimacum Creek.

REC #	TYPE	RM	LOCATION	RECOMMENDATION CATEGORY	RECOMMENDATION	PRIORITY	CONSIDERATIONS
21	Restoration		Barnhouse Creek	Evaluate Potential for Wetland Restoration	Evaluate potential for wetland restoration in site of historic perennial wetland.	Medium	Alternatively, establish riparian vegetation (see Box 20).
22	Data Gap	10.3-11.2	Main Stem - Confined reach on slope of glacial terrace	Analysis	There is a road along the river where beavers have established - hydraulic modeling and assessment of threat to road.	Low-Medium	Opportunity to roughen channel and add complexity here, but need field assessment of morphology and infrastructure. Lidar resolution diminishes in forest.
23	Restoration	13.5-13.7	On glacial terrace, just downstream of Delanty Lake	Riparian Vegetation	Establish riparian vegetation along ditched reach.	Medium	
24	Protection	ECH 1.2-1.6	East Fork	Riparian Vegetation	Protect and enhance riparian vegetation from previous restoration; 2015 imagery shows very small/sparse vegetation	High	Consider existing beaver dams in this reach when enhancing riparian vegetation.
26	Restoration	ECH 2.2-2.9	East Fork	Riparian Vegetation	Establish riparian vegetation along ditched reach.	Medium	
27	Restoration	ECH 2.8-3.4	East Fork	Evaluate Potential for Wetland Restoration	Evaluate potential for wetland restoration in site of historic perennial wetland.	Medium-High	Consider enhancing habitat complexity via wetland restoration or placement of large wood or re-meandering in either this location or see Recommendation #29. There are long stretches with low complexity through these portions of the east fork, and improving habitat through one or both of these reaches could improve habitat connectivity in east fork Chimacum.
28	Restoration	ECH 3.3-4.4	East Fork	Riparian Vegetation	Establish riparian vegetation along ditched reach.	Medium	

REC #	TYPE	RM	LOCATION	RECOMMENDATION CATEGORY	RECOMMENDATION	PRIORITY	CONSIDERATIONS
29	Restoration	ECH 4.3-4.7	East Fork	Evaluate Potential for Wetland Restoration	Evaluate potential for wetland restoration in site of historic perennial wetland.	Medium-High	See note in Recommendation #27.
30	Restoration	SWA 0.3-0.0	Swansonville Creek	Riparian Vegetation	Establish riparian vegetation along ditched reach	Medium	
31	Data Gap	SWA 0.3	Swansonville Creek	Analysis	Investigate possible causes of DO exceedance at SWA 0.3 since contributing area is fairly small	Medium	
32	Data Gap	ECH 5.6-6.0	East Fork, confined reach on slope of glacial terrace	Analysis	REM is poor here due to lidar resolution in dense forest. Possible opportunities to place wood and create channel complexity, but needs analysis and better spatial data	Low	

Appendix 2

Annotated Bibliography

Natural Systems Design

THIS PAGE INTENTIONALLY LEFT BLANK

The following sources were reviewed to provide background into previous work directly relevant to the Chimacum Creek watershed.

Bahls, P., & Rubin, J. (1996). Chimacum watershed coho salmon habitat restoration assessment. Kingston, WA.

This watershed assessment addresses limiting factors for native coho and summer chum in the watershed, with a focus on comparing reconstructed historical conditions to current conditions. The report presents original data on fish abundance and geomorphic habitat features (pools, wood, gravels) that were collected during 1995. The report additionally presents historical data from the Government Land Office (GLO) surveys and a historical timeline of events in the watershed, based on numerous sources.

Bahls, P. (2000). Chimacum Headwaters Restoration Project Monitoring Report.

This report documents conditions in Chimacum Creek at the location of restoration on the Barnhouse property which was implemented during May 1999 to March 2000. Projects included fencing of the channel, placement of large wood and root wads in the channel, re-meandering 600' of channel, and planting riparian vegetation including native trees and shrubs. The intent was to create a foundation for continued annual monitoring by establishing photo locations, vegetation transects, and stream channel transects, and by observing fish spawning. The bulk of this report shows initial photographs from each designated photo location.

Correa, G. (2002). Salmon and Steelhead Habitat Limiting Factors, Water Resource Inventory Area 17, Quilcene/Snow Basin: Final Report.

This watershed assessment steps through the habitat limiting factors in Chimacum Creek, including assessing coho rearing and spawning habitat. They present redd counts from WA Department of Fish and Wildlife and discuss previously-presented, but conflicting, conclusions regarding the health of Chimacum Coho.

Elsner, M. M., Cuo, L., Voisin, N., Deems, J. S., Hamlet, A. F., Vano, J. A., … Lettenmaier, D. P. (2010). Implications of 21st century climate change for the hydrology of Washington State. Climatic Change, 102(1-2), 225–260. http://doi.org/10.1007/s10584-010-9855-0

This study addresses climate change impacts on three types of watersheds in Washington state: rain-dominated, rain-snow dominated and snow-dominated. By using projected future climate as the meteorological input to hydrology models, the authors demonstrate climate change effects on streamflow. The study does not specifically discuss the Chimacum Creek watershed, but results for rain-dominated watersheds are relevant to future conditions in Chimacum Creek.

Gately, G., Clarke, J., Ecelberger, D., & Schrader, C. (2015). Chimacum Watershed Water Quality and Fishes: A Comprehensive Review. Olympia, WA. Retrieved from http://www.jeffersoncd.org/wp-content/uploads/2015/05/Chimacum-Report-with-appendices_4-24-15.pdf

This report presents data and analysis relevant to water quality, fish abundance, restoration, riparian buffers in the watershed. Recent water quality data, including temperature, pH, dissolved oxygen (DO), turbidity, and fecal coliform, are presented for 28 monitoring stations. Analysis focuses on water quality trends and possible drivers, and the status of riparian vegetation and fish abundance. Discussion focuses on meeting a diverse set of needs for fish, wildlife and humans.

Simonds, F. W., Longpré, C. I., & Justin, G. B. (2004). Ground-Water System in the Chimacum Creek Basin and Surface Water/Ground Water Interaction in Chimacum and Tarboo Creeks and the Big and Little Quilcene Rivers, Eastern Jefferson County, Washington. Reston, Virginia.

This investigation describes field data and analysis to quantify spatial variations in surface water-ground water interactions in the Chimacum Creek watershed. The authors conclude that the creek receives an average net gain of 5-7 cubic feet per second (cfs) of streamflow from groundwater sources, but that the amount and direction of surface water-ground water interaction vary spatially.

Smayda Environmental Associates. (2001). West Fork Chimacum Creek near RM 6: Design Report for replacing an undersized box culvert and restoring 2200 feet of stream and buffer to improve salmon habitat.

This report describes existing conditions, geomorphology, and hydrology (specifically, design flows) for Chimacum Creek, south of RM 6. The report was the design for replacing an undersized box culvert with a bridge, and restoring 2200' of stream and buffer, including re-meandering portions of the channel, installing large wood, and riparian planting. They find that existing conditions include a shortage of riffles and pools, mostly sand substrate and reed canary grass as the dominant vegetation.