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Cowiche Creek

Vegetation and Shade Study

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COVER PHOTO: Cowiche Creek near mouth, looking downstream (photo by Tighe Stuart).

Cowiche Creek

Vegetation and Shade Study

by

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Abstract

In 2004, the Washington State Department of Ecology (Ecology) conducted the Naches River Temperature Total Maximum Daily Load (TMDL) study (Brock, 2004). The study included the Cowiche Creek Watershed, a subbasin within the Naches River Basin. Ecology developed the Upper Naches River Temperature TMDL (Brock, 2008), which recommended system potential vegetation scenarios for Cowiche Creek as load allocations for water temperature.

The 2008 report based the system potential vegetation recommendations for the Cowiche Creek Watershed on vegetation characteristics from the Upper Naches River. Those recommendations may not be appropriate for those parts of the Cowiche Creek Watershed that are lower in elevation and have less precipitation than most of the Naches River Watershed.

As part of the Cowiche Creek vegetation and shade study, in 2012 and 2013 Ecology collected additional hemispherical photography and conducted brief vegetation surveys at sites in Cowiche Creek and its tributaries. The data from these sites supplement data collected during the 2004 study.

This report will support the Upper Naches River and Cowiche Creek Temperature TMDL implementation strategy (Peterschmidt, 2010) by recommending system potential vegetation specifically for the Cowiche Creek Watershed. The report presents an analysis of the current vegetation and shade, as well as system potential shade simulated by Ecology's Shade model, for Cowiche Creek and its tributaries.

Introduction

In 2010, Ecology completed a TMDL study for temperature in the upper Naches River and Cowiche Creek (Brock, 2008; Whiley, 2003; Peterschmidt, 2010). The TMDL established load allocations for nonpoint sources and wasteload allocations for point sources to reduce water temperatures. The study also included a detailed assessment of current and system potential shade and temperature for the upper Naches River.

For Cowiche Creek, the TMDL recommended that the system potential mature riparian vegetation (system potential vegetation) to be used as a surrogate for load allocations for temperature. *System potential mature riparian vegetation is defined as: that vegetation which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology, and hydrologic processes*.

The TMDL recommended system potential vegetation that consisted of a 2-zone gallery of trees with 5 meters of mixed deciduous/conifers backed by another 41 meters of conifers, based on potential system vegetation along the upper Naches River. This system potential riparian vegetation description is not appropriate for the Cowiche Creek Watershed, which is lower in elevation than most of the Naches River Watershed and also descends through lands with much lower precipitation. In addition, with more than a quarter of the watershed in agriculture, irrigation plays a major role in the types of vegetation that can grow in certain parts of the watershed.

To assist with the implementation of the 2010 TMDL, this 2013 study of vegetation and shade in the Cowiche Creek Watershed (1) details the current system vegetation and effective shade and (2) provides a description of system potential vegetation throughout the watershed. The system potential vegetation zones and associated characteristics provide details to estimate the system potential effective shade. A shade deficit map shows where shade improvements are needed the most throughout the study area.

Study Area

Cowiche Creek and its tributaries drain a range of foothills of the eastern Cascade Mountains in central Washington, emptying into the Naches River near the city of Yakima (Figure 1). The Cowiche Watershed is a subbasin within Water Resource Inventory Area 38 (Naches). It encompasses 120 square miles (approximately 77,100 acres). Major streams in this watershed include South Fork (SF) Cowiche Creek, North Fork (NF) Cowiche Creek, and Reynolds Creek. The watershed spans two major ecoregions: the Eastern Cascades Slopes and Foothills, and the Columbia Plateau. The climate within the watershed varies dramatically, with parts of the Divide Range along the western edge of the watershed receiving as much as 50 inches of precipitation per year, while the eastern edge of the watershed receives less than 10 inches of precipitation per year. Natural land cover reflects this, with thick forests in the west giving way to desert in the east.

The main land-use activities in the watershed are canyon/rangeland (40%), forest (32%), and agriculture (28%). Urban areas, including the towns of Tieton and Cowiche, cover 0.5% of the watershed. Land ownership within the watershed is a mix of public (39%) and private (61%). Public lands in the watershed are managed primarily by the Washington State Department of Natural Resources (29% of watershed), Washington Department of Fish and Wildlife (7% of watershed), and the U.S. Forest Service (3% of watershed).

French Canyon Reservoir is part of NF Cowiche Creek. The Tieton Canal carries water from the Tieton River into the Cowiche Creek Watershed. The canal empties into the French Canyon Reservoir, created by a dam on NF Cowiche Creek, for irrigation water storage. NF Cowiche Creek upstream of the French Canyon Reservoir is an intermittent stream. Downstream of the reservoir, water from the Tieton Canal system and irrigation withdrawals and returns strongly influence the amount of water in NF Cowiche Creek.

SF Cowiche Creek and Reynolds Creek, on the other hand, receives water mainly from its headwater streams in the foothills of the Cascade Mountains. They are both perennial streams.

Cowiche Creek supports steelhead and coho salmon (Haring, 2001). Bull trout have been reported in the upper watershed, but it is unknown if there is currently a resident population (Tobin, 2013; personal communication). The Yakima Nation is in its Phase II of the Yakima Basin Coho reintroduction. It has a mobile acclimation unit on SF Cowiche Creek at the WA Fish Wildlife's Cowiche Wildlife Area (Newsome, 2010). Each year, starting in 2009, 10,000 coho smolts are acclimated and released into SF Cowiche Creek. Fish survival and return rates vary year to year.

There are currently five fruit-packing facilities and one wastewater treatment plant that discharge to streams in the Cowiche Creek Watershed. The Upper Naches River Temperature TMDL (Brock, 2008) calculated the wasteload allocations for temperature for these facilities.

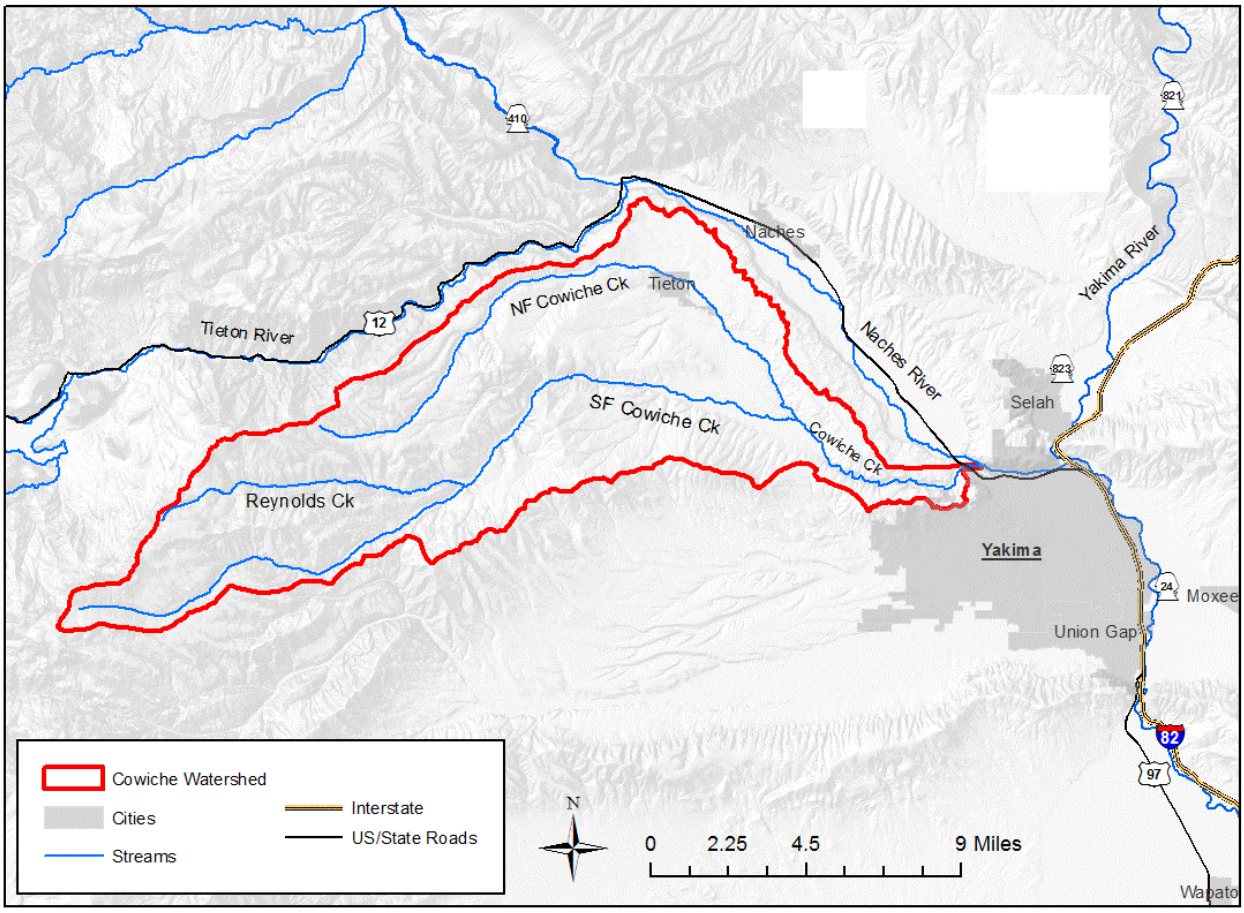

Figure 1: Map of the study area within the Cowiche Creek Watershed.

Existing or Ongoing Studies

During the 2004 data collection for the Upper Naches River Temperature TMDL (Brock, 2008), hemispherical photos of riparian vegetation were taken at a number of locations on Cowiche Creek, NF Cowiche Creek, Reynolds Creek, and SF Cowiche Creek. Channel surveys, including bankfull width and other measures relating to channel geometry, were performed at sites on Cowiche Creek and SF Cowiche Creek.

In summer of 2013, Ecology collected continuous temperature data at several locations on NF Cowiche as part of the Yakima Area Creeks Temperature Assessment (Dugger, 2013). A summary report was not written, but the temperature data are accessible to the public through Ecology's Environmental Information Management database.

Previous Work

The North Yakima Conservation District (NYCD) has been working in the Cowiche Creek Watershed since 2004, and it has implemented various projects to improve streamflow, fish passage, and riparian habitat (NYCD, 2009).

On the SF Cowiche Creek, NYCD projects included the Thornton Instream and Riparian Habitat Improvement in 2004, Snow Mountain Ranch Barrier Removal and Habitat Improvement in 2005, and Upper Lust Fish Passage in 2006. On Cowiche Creek, projects included the Cowiche Creek Water Users Association Diversion Removal and Trust Water in 2004, Garretson Fish Screen and Barrier Removal in 2005, Schneider, Green, and Wilkinson Habitat Restoration in 2007, and Cowiche Creek Siphon Fish Passage in 2017.

Goals and Objectives

The goals of this study were to:

- Provide information about where shade is needed the most in the watershed.
- Provide details about the system potential riparian vegetation.

The primary objectives of this study were to:

- Quantify current vegetation and shade throughout the Cowiche Creek Watershed.
- Characterize the current vegetation in terms of species composition and physical attributes.
- Characterize the system potential vegetation in terms of species composition and physical attributes.
- Develop shade models that simulate current effective shade and system potential shade.
- Create a map showing where there are shade deficits throughout the study area in the Cowiche Creek Watershed.

Methods

Field Studies

Reference Sites

In 2012 and 2013, reference sites were selected at locations for sampling which best represented undisturbed natural riparian vegetation in different parts of the watershed. These included mature riparian vegetation and a diversity of native trees and shrubs (Stuart, 2013). A summary of the reference site data from 2012 and 2013 is presented in Appendix A.

Each reference site was visited once during the growing season. Hemispherical photos were taken to estimate shade. Photos were taken from stream center to measure shade on the creek. Photos were taken from both left and right banks in the riparian zone to measure canopy shade. Bankfull width and stream aspect were also measured at each site. A brief vegetation survey was conducted at each site to record the vegetation species along with corresponding vegetation height and density. These reference sites were used to calibrate a Shade model (see below). Reference sites are shown in Figure 2 and Table 1.

Some sites were visited during the 2004 Upper Naches River TMDL study. Vegetation surveys were not conducted during the 2004 study, but the study did take hemispherical photos. The shade calculated from the 2004 hemispherical photos were also used to calibrate the Shade model.

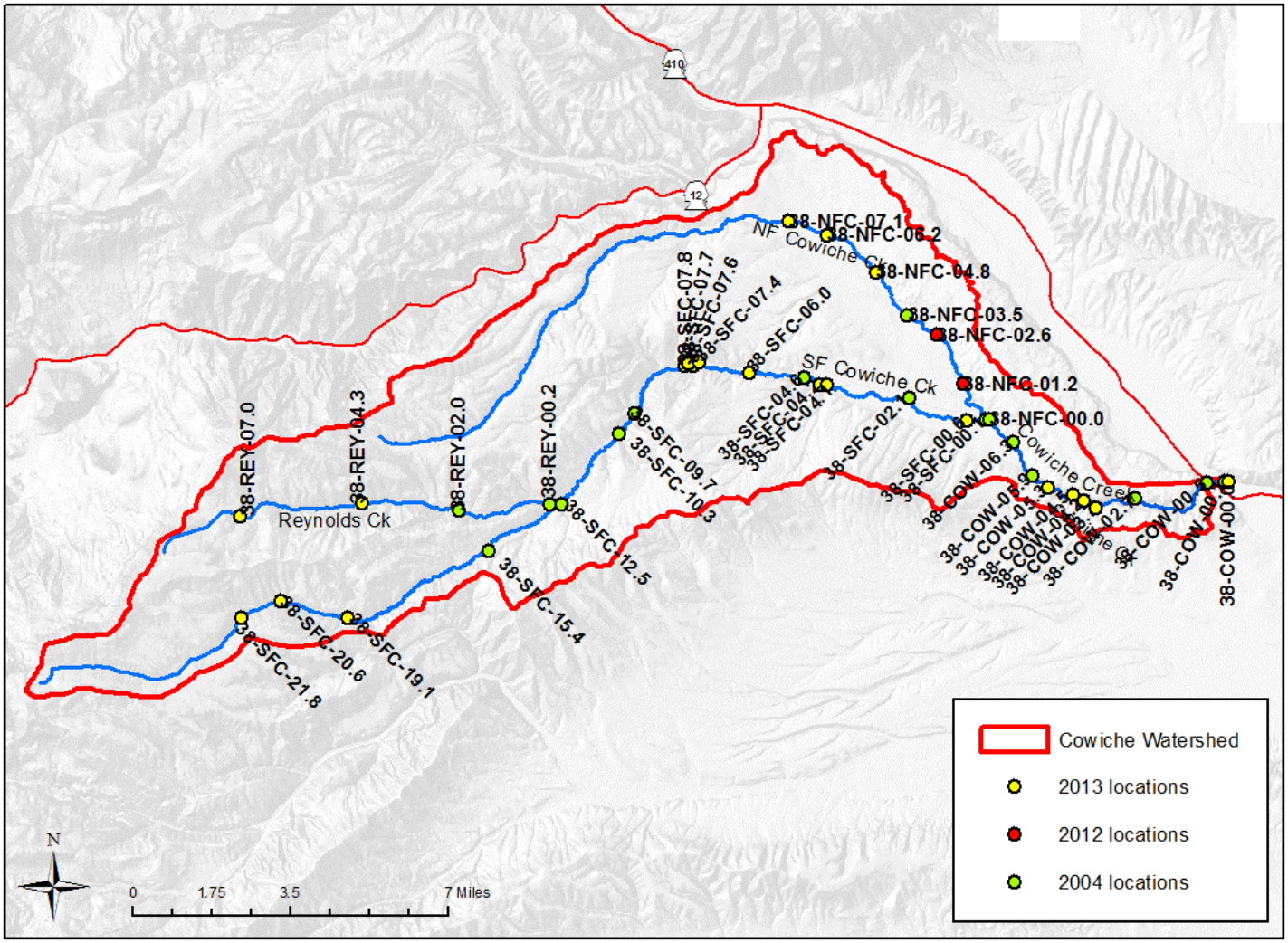

Figure 2: Map of the locations surveyed in 2004, 2012, and 2013.

Table 1: List of sites sampled in 2012 and 2013 and for the 2004 Upper Naches River and Cowiche Creek TMDL.

Site ID	Description	Latitude	Longitude	Year sampled
38-SFC-21.8	SF Cowiche Ck. abv Fall Ck.	46.58270	-121.03034	2013
38-SFC-20.6	SF Cowiche Ck. blw Fall Ck.	46.58810	-121.01192	2013
38-SFC-19.1	SF Cowiche Ck. 2 mi blw Fall Ck.	46.58269	-120.98042	2013
38-SFC-07.8	SF Cowiche Ck. Oak Ck. Wildlife Area 1	46.66459	-120.82355	2013
38-SFC-07.7	SF Cowiche Ck. Oak Ck. Wildlife Area 2	46.66509	-120.82230	2013
38-SFC-07.4	SF Cowiche Ck. Oak Ck. Wildlife Area 3	46.66568	-120.81709	2013
38-SFC-06.0	SF Cowiche Ck. Oak Ck. Wildlife Area 5	46.66220	-120.79372	2013
38-SFC-04.2	SF Cowiche Ck. Snow Mtn. Ranch 1	46.65866	-120.76072	2013
38-SFC-04.1	SF Cowiche Ck. Snow Mtn. Ranch 2	46.65839	-120.75718	2013
38-SFC-00.6	SF Cowiche Ck. blw Summitview Rd.	46.64694	-120.69207	2013
38-REY-07.0	Reynolds Ck. near end of C1000 road	46.61512	-121.03123	2013
38-REY-04.3	Reynolds Ck. mid-watershed	46.61985	-120.97425	2013
38-NFC-07.1	NF Cowiche Ck. at Noye Rd.	46.71099	-120.77522	2013
38-NFC-06.2	NF Cowiche Ck. at Washington St. in Tieton	46.70668	-120.75745	2013
38-NFC-04.8	NF Cowiche Ck. near old Tieton WWTP	46.69482	-120.73444	2013
38-NFC-02.6	NF Cowiche Ck. abv Cowiche WWTP outfall	46.67459	-120.70579	2012
38-NFC-01.2	NF Cowiche Ck. abv Thompson Rd	46.65893	-120.69355	2012
38-COW-05.3	Cowiche Ck. Cowiche Canyon 1	46.62546	-120.65392	2013
38-COW-04.5	Cowiche Ck. Cowiche Canyon 2	46.62331	-120.64220	2013
38-COW-04.2	Cowiche Ck. Cowiche Canyon 3	46.62138	-120.63680	2013
38-COW-03.7	Cowiche Ck. Cowiche Canyon 4	46.61905	-120.63163	2013
38-COW-00.0	Cowiche Ck. at mouth	46.62774	-120.56954	2013
38-SFC-15.4	SF Cowiche Ck. Trans6, nr Pine Mountain	46.60450	-120.91500	2004
38-SFC-12.5	SF Cowiche Ck. Trans7, just below Reynolds Ck.	46.61966	-120.88036	2004
38-SFC-10.3	SF Cowiche Ck. Trans11, Cowiche Basin 1	46.64260	-120.85430	2004
38-SFC-09.7	SF Cowiche Ck. Trans12, Cowiche Basin 2	46.64910	-120.84701	2004
38-SFC-07.6	SF Cowiche Ck. Trans8, Oak Ck. Wildlife Area	46.66459	-120.81997	2004
38-SFC-04.6	SF Cowiche Ck. Trans9, Sunset Rd.	46.66075	-120.76770	2004
38-SFC-02.1	SF Cowiche Ck. Trans10, Pioneer Way	46.65435	-120.71870	2004
38-SFC-00.1	SF Cowiche Ck. Tran5, N Pioneer Way just abv confluence	46.64733	-120.68314	2004
38-REY-02.0	Reynolds Ck. T13N R15E s14	46.61749	-120.92893	2004
38-REY-00.2	Reynolds Ck. nr confluence	46.61980	-120.88676	2004
38-NFC-03.5	NF Cowiche Ck. Naches-Tieton Rd.	46.68092	-120.71967	2004
38-NFC-00.0	NF Cowiche Ck. at Mouth, Mahoney Rd.	46.64759	-120.68125	2004
38-COW-06.3	Cowiche Ck. Trans4, Weikel Rd.	46.64000	-120.67000	2004
38-COW-05.9	Cowiche Ck. Trans3, upper end of Cowiche Canyon	46.62947	-120.66124	2004

Site ID	Description	Latitude	Longitude	Year sampled
38-COW-02.7	Cowiche Ck. Trans2, Cowiche Canyon Rd.	46.62222	-120.61314	2004
38-COW-00.5	Cowiche Ck. Trans1, W Powerhouse Rd.	46.62735	-120.57971	2004
38-COW-00.1	Cowiche Ck. nr Mouth	46.62765	-120.57125	2004

Current Vegetation and Shade Analysis

Ecology digitized near-stream vegetation from the 2013 National Agricultural Imagery Program (NAIP) color digital orthophotos of Cowiche Creek, NF Cowiche Creek up to French Canyon Dam, SF Cowiche Creek, and Reynolds Creek. The NAIP photos are from July 3, 2013 with the exception of the top end of SF Cowiche Creek, taken on August 20, 2013. Polygons within 500ft of the stream center, delineating different types of vegetation, were digitized at a 1:2000 scale using ArcGIS®. Using vegetation categories established during the Shade model development (see below), each polygon was assigned a vegetation category (Table 2) similar to the 2004 Upper Naches TMDL (Brock, 2008).The resulting GIS vegetation layer was then sampled at 100-meter intervals along the length of each stream using TTools (ODEQ, 2005). This produced the inputs for Ecology's Shade model (Ecology, 2003).

Ecology's Shade model quantifies the solar radiation above and below the vegetation canopy and accounts for topographic features such as hills. It calculates effective shade as the reduction in solar radiation at the water surface. Each vegetation category in Table 2 was assigned unique attributes for vegetation height, density, and overhang in the Shade model, which the model used to estimate shade. Estimated shade from the model was compared to calculated shade from hemispherical photos taken at reference sites (Figure 3). Hemispherical photos were analyzed using HemiView canopy analysis software (University of Kansas, 1996). The results represent the effective shade under the current vegetation.

The current system effective shade was averaged over 1,000m intervals, starting at the mouth of each creek. These averages are used to calculate the shade deficit, or the amount of shade needed to achieve system potential effective shade, throughout the watershed.

Table 2: Riparian vegetation categories for the Cowiche Creek Watershed.

Code	Source	Description	Height (m)	Density (%)	OH (m)
111	ECY	css- conifer, small, sparse	17	25%	1.7
112	ECY	csm- conifer, small, medium	17	50%	1.7
113	ECY	csd- conifer, small, dense	17	75%	1.7
121	ECY	cms- conifer, medium, sparse	29	25%	2.9
122	ECY	cmm- conifer, medium, medium	29	50%	2.9
123	ECY	cmd- conifer, medium, dense	29	75%	2.9
131	ECY	cls- conifer, large, sparse	38	25%	3.8
132	ECY	clm- conifer, large, medium	38	50%	3.8
133	ECY	cld- conifer, large, dense	38	75%	3.8
211	ECY	mss- mixed, small, sparse	15	25%	1.5
212	ECY	msm- mixed, small, medium	15	50%	1.5
213	ECY	msd- mixed, small, dense	15	75%	1.5
221	ECY	mms- mixed, medium, sparse	25.5	25%	2.6
222	ECY	mmm-mixed, medium, medium	25.5	50%	2.6
223	ECY	mmd- mixed, medium, dense	25.5	75%	2.6
231	ECY	mls-mixed, large, sparse	35.5	25%	3.6
232	ECY	mlm- mixed, large, medium	35.5	50%	3.6
233	ECY	mld- mixed, large, dense	35.5	75%	3.6
311	ECY	dss- deciduous, small, sparse	13	25%	1.3
312	ECY	dsm- deciduous, small, medium	13	50%	1.3
313	ECY	dsd- deciduous, small, dense	13	75%	1.3
321	ECY	dms- deciduous, medium, sparse	22	25%	2.2
322	ECY	dmm- deciduous, medium, medium	22	50%	2.2
323	ECY	dmd- deciduous, medium, dense	22	75%	2.2
331	ECY	dls- deciduous, large, sparse	33	25%	3.3
332	ECY	dlm- deciduous, large, medium	33	50%	3.3
333	ECY	dld- deciduous, large, dense	33	75%	3.3
400	ECY	r- riparian scrub/ shrub	4	75%	0.4
401	ECY	s- scrub/ shrub upland	1	25%	0.1
500	ECY	g- grass/ rush/ sedge riparian	1	50%	0.1
600	ECY	b- barren/road/rock	0	0%	0
601	ECY	be- barren/ embankment	0	0%	0
602	ECY	meadow or open desert ground	0	0%	0
700	ECY	w- water	0	0%	0
800	ECY	d- developed	6	75%	0.6
850	ECY	c- pastures, cultivated	0	0%	0
870	ECY	o- orchard	3	50%	0.3
1000	ECY	wb- water flows under bridge	10	100%	0

Code	Source	Description	Height (m)	Density (%)	OH (m)
2000	ECY	wc- water flows under road, via culvert	0	100%	0
3000	ECY	hh- house / houses	6	50%	0.6
4000	ECY	rd - roads	0	0%	0

This study used the same codes, sources, descriptions, and densities as the Upper Naches River Temperature TMDL (Brock 2008). The heights for the vegetation categories were established using the 2012 and 2013 vegetation data collected in the Cowiche Creek Watershed. Similar to the 2004 TMDL, overhang (OH) was designated at 10% of the vegetation heights except for the mixed vegetation categories. The mixed vegetation categories are an average between the conifers and deciduous vegetation categories.

Figure 3: Example of a hemispherical photograph taken from the center of SF Cowiche Creek.

System Potential Vegetation and Shade Analysis

System potential riparian vegetation was determined for the four major streams in the study area. This is also known as the system potential *mature* riparian vegetation, which is defined as that vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

Riparian vegetation in the Cowiche Watershed can be defined according to four system potential vegetation zones: Riparian/Shrub, Deciduous, Mixed, and Coniferous.

This study used a soils-based analysis to determine vegetation zones. It used a GIS coverage of soil types in the Cowiche Creek Watershed obtained from the U.S. Department of Agriculture (USDA)/Natural Resource Conservation Service (NRCS)'s SSURGO soil layer.

For each soil type, potential vegetation zones were defined based on a weight of evidence from the following sources:

- **Reference Site Data** – Vegetation survey data from reference sites visited during this project.
- **USDA Ecological Site/Plant Association data** – For each soil type in USDA/ NRCS soil survey, the characteristic associated forest and/or rangeland plant community is defined.
- **USDA Forestland Productivity data** – For each soil type in the USDA/NRCS soil survey that supports forestland, a site index is provided for one or more tree species. The site index value represents the height of trees that can grow on that soil at age 50 or 100 years.
- **General Land Office (GLO) surveys** – The General Land Office surveyed all township and section lines during the late 1800s. Surveyors often made notes of vegetation present along streams; these records are now available online through the Bureau of Land Management (www.blm.gov/or/landrecords/survey/ySrvy1.php).

System potential vegetation height, density, and overhang values for each vegetation zone were defined based on 2012 and 2013 reference sites data. As described above, the 2012 and 2013 reference sites represent locations with undisturbed mature riparian vegetation. The measured tree heights at 2012 and 2013 reference sites were typically taller than tree heights in the USDA's Forestland Productivity Data.

Since irrigation is a major component of the watershed, particularly in Cowiche Creek, NF Cowiche Creek, and SF Cowiche Creek, the system potential vegetation for these creeks are based on the mature vegetation that could grow under the current irrigation conditions. This is supported by the data collected at the 2012 and 2013 reference sites.

Using the system potential vegetation zones and associated characteristics, the Shade model was used to estimate system potential effective shade (shade produced by system potential vegetation) on the simulated stream reaches in the watershed. The system potential effective shade was averaged at 1,000-meter (m) intervals, starting at the mouth of each creek. These averages were used to calculate the shade deficit.

Results and Discussion

Current Vegetation and Shade Analysis

Using Ecology's Shade model (Ecology, 2003), Ecology simulated current effective shade for Cowiche Creek, NF Cowiche Creek, SF Cowiche Creek, and Reynolds Creek. Figures 4-8 show the simulation results along with HemiView estimates of effective shade. Appendix B, Table B-1 lists the HemiView effective shade estimates at reference sites.

Overall, the current effective shade values produced by the Shade model compared well with the HemiView shade estimates for each of the four streams. The simulated current effective shade in Cowiche Creek was moderately variable and generally below 50% effective shade. The simulated current effective shade in NF Cowiche Creek was also variable but generally above 50% effective shade.

The simulated current effective shade in SF Cowiche Creek was highly variable, except for the top quarter of the stream, which was highly shaded, mostly above 90% effective shade. The simulated current effective shade in Reynolds Creek was also highly variable, except for the top half of the stream, which was highly shaded, also above 90% effective shade.

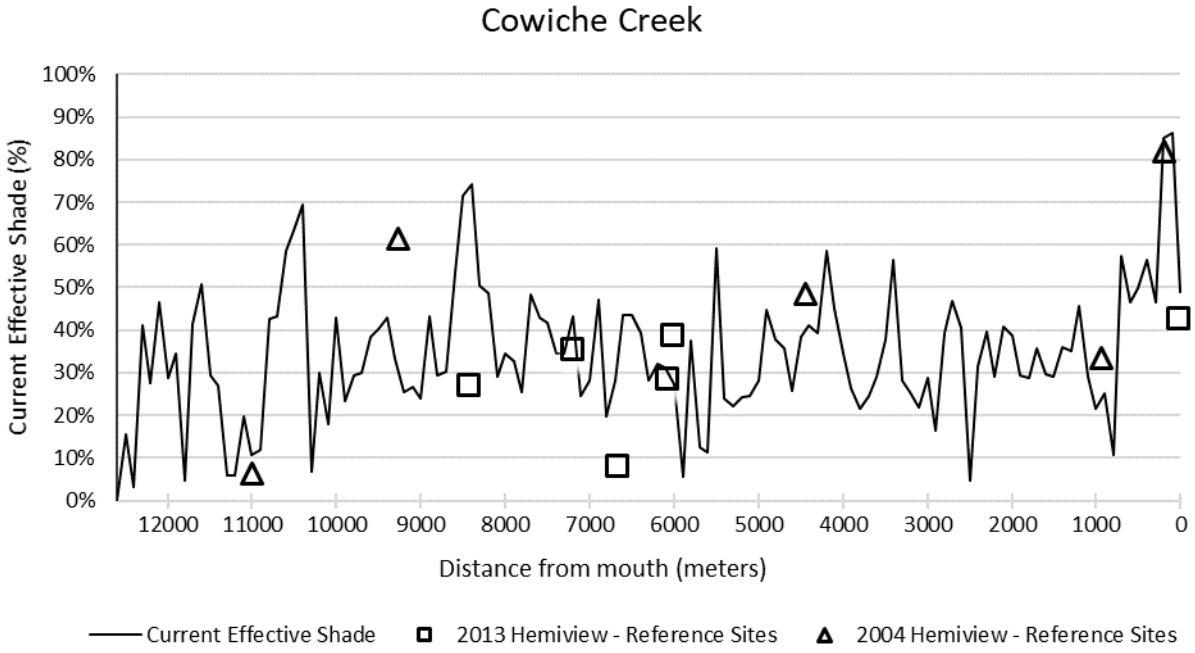

Figure 4: Simulated current effective shade on Cowiche Creek, including the HemiView analysis results from the surveyed sites.

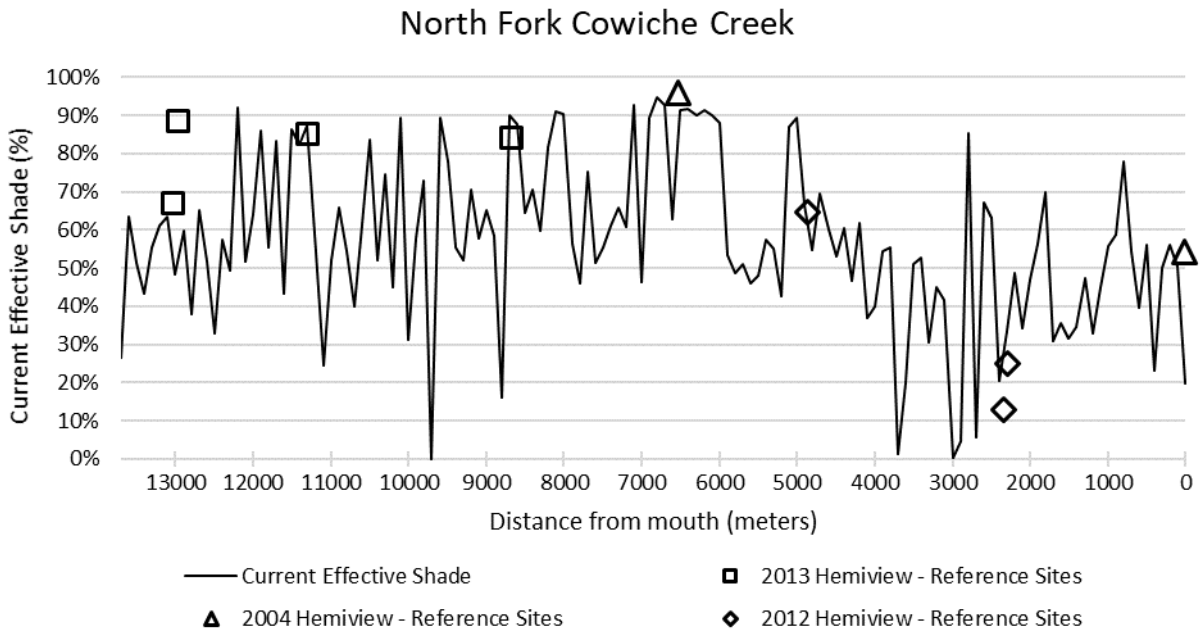

Figure 5: Simulated current effective shade on NF Cowiche Creek, including the HemiView analysis results from the surveyed sites.

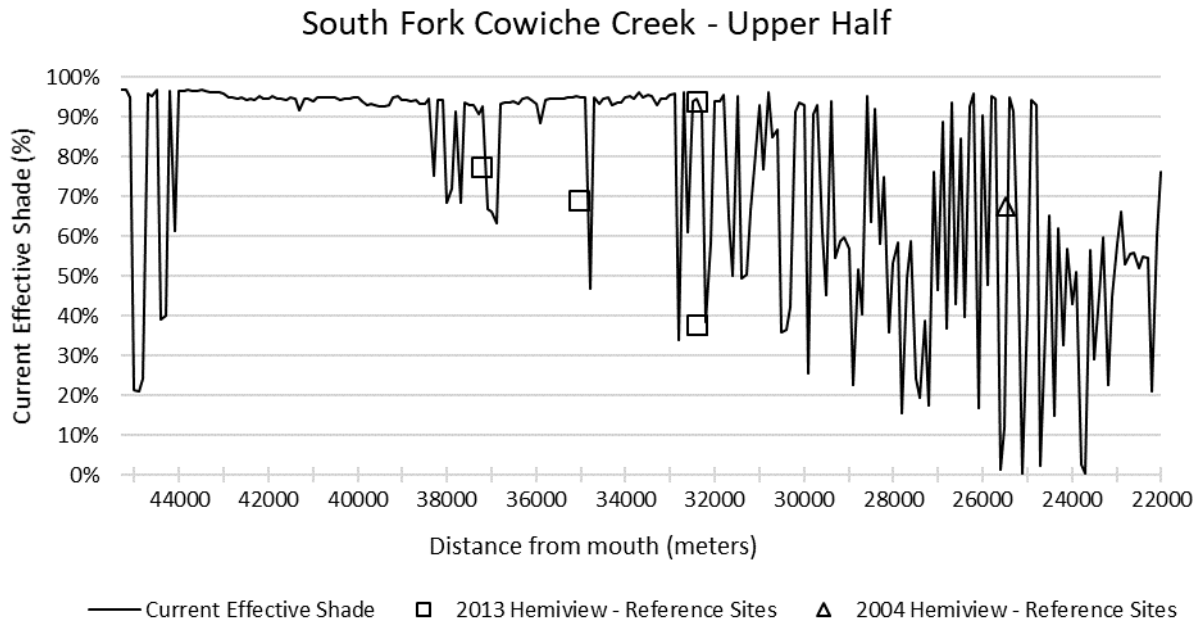

Figure 6: Simulated current effective shade on the upper half of SF Cowiche Creek, including the HemiView analysis results from the surveyed sites.

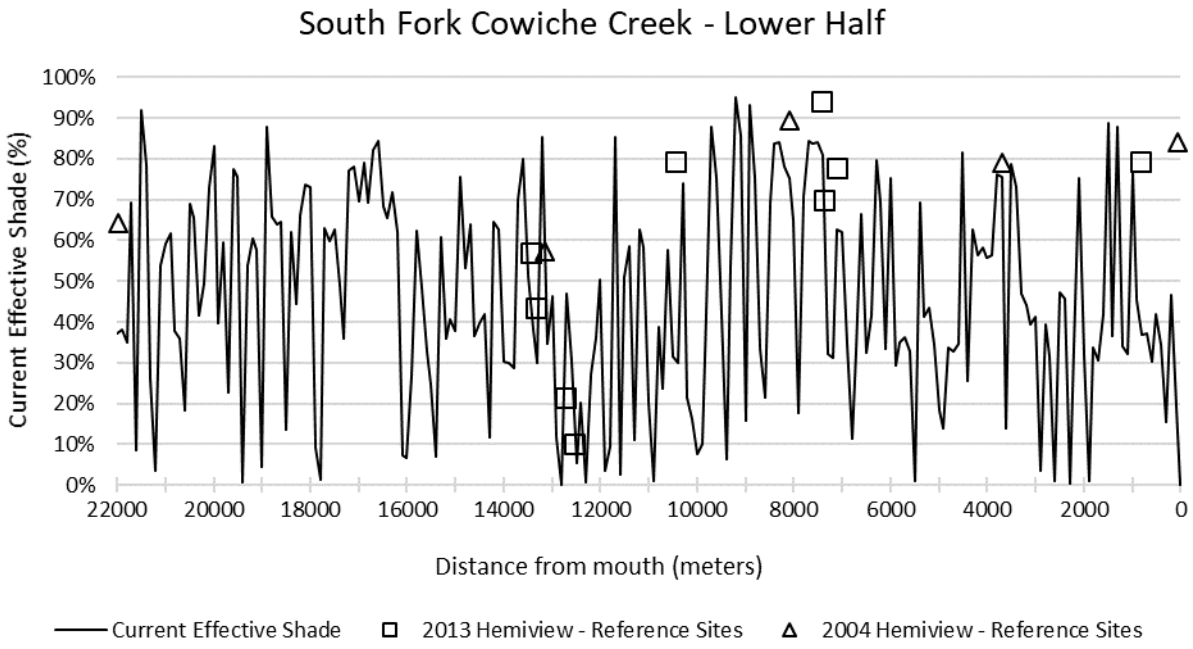

Figure 7: Simulated current effective shade on the lower half of SF Cowiche Creek, including the HemiView analysis results from the surveyed sites

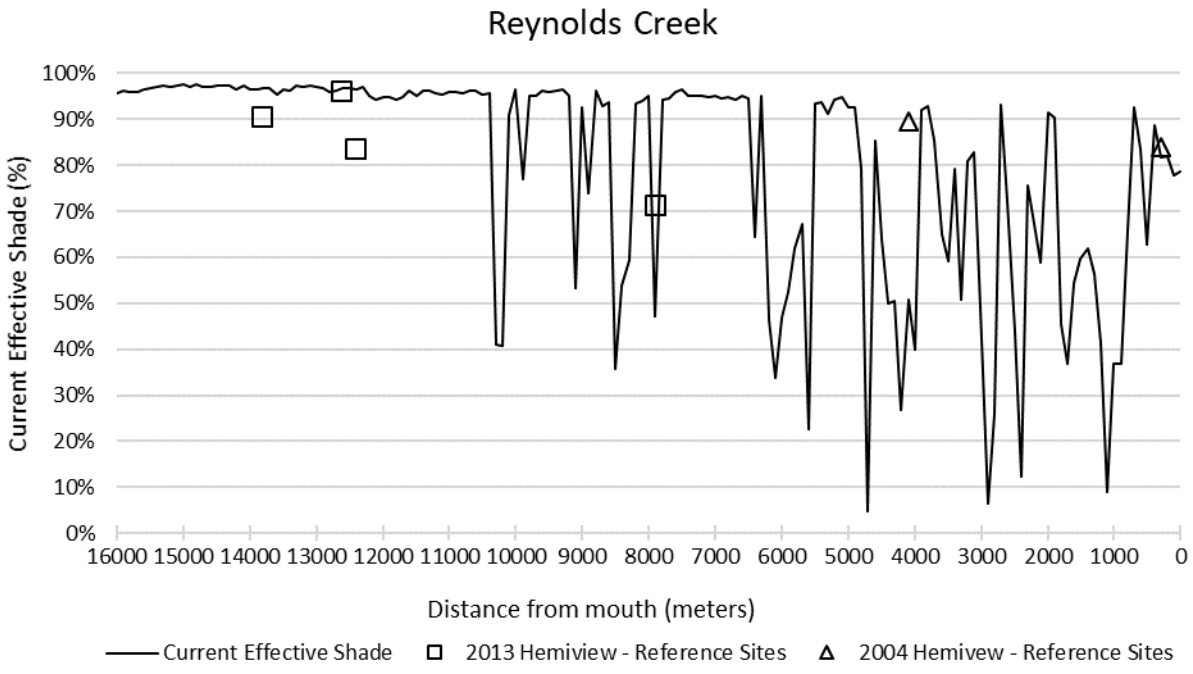

Figure 8: Simulated current effective shade on Reynolds Creek, including the HemiView analysis results from the surveyed sites.

Potential Vegetation and Shade Analysis

Based on Ecology's analysis, the system potential riparian vegetation in the Cowiche Creek Watershed falls within four vegetation zones: Riparian/Shrub, Deciduous, Mixed, and Coniferous. System potential riparian vegetation is defined as that native vegetation which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology, and hydrologic processes. The system potential vegetation zones are shown in Figure 8 and Table 3.

The Riparian/Shrub vegetation zone is in the lower and drier elevations with soils that mainly support shrubs and grasses. The entire length of Cowiche Creek as well as the portion of NF Cowiche Creek from below the town of Tieton down to its mouth, is in this zone. It consists mainly of willows (*Salix sp.)* and red osier dogwood (*Cornus sericea*) with an understory of rose (*Rosa sp.*) and snowberry (*Symphoricarpus alba*) with a height of 5m, 65% density, and 0.5m overhang.

The Deciduous vegetation zone is found in NF Cowiche Creek, below the French Canyon Reservoir down to below of the town of Tieton, and through the lower reaches of SF Cowiche Creek, just above the agricultural area down to its mouth. In this vegetation zone, the dominant vegetation species are black cottonwood (*Populus trichocarpa*), red osier dogwood, with other deciduous trees, such as Garry oak (*Quercus garryana*), Alder (*Alnus incana*), and Elderberry (*Sambucus cerulea),* in the upper sections of the zone. The understory is mainly willows, rose, and snowberry. This zone is represented by heights of 18m, 60% density, and 1.8m overhang.

The Mixed vegetation zone is representative of the transition into a coniferous dominant zone found much higher in the watershed. On SF Cowiche Creek, this zone starts just above the agricultural areas and continues up to approximately 3 miles above the confluence with Reynolds Creek. This vegetation zone also includes the lower reaches of Reynolds Creek. Black cottonwood, aspens (*Populus tremuloides*), alder, and Garry oak mixed with grand fir (*Abies grandis*), Douglas fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*) are the dominant vegetation species. The understory consists of willows, Douglas fir, vine maples (*Acer glabrum* and *Acer circinatum*), and snowberry. This zone is represented by a height of 30m, 40% density, and 2.2m overhang.

The Coniferous vegetation zone consists of grand fir, Douglas fir, Engelmann spruce (*Picea engelmannii*), western larch (*Larix occidentalis*), and ponderosa pine. The understory is mainly composed of willows and alders, transitioning into currant (*Ribes sp*.) and snowberry near the upper portions of the zone. This zone is represented by a height of 36m, 35% density, and 3.6m overhang.

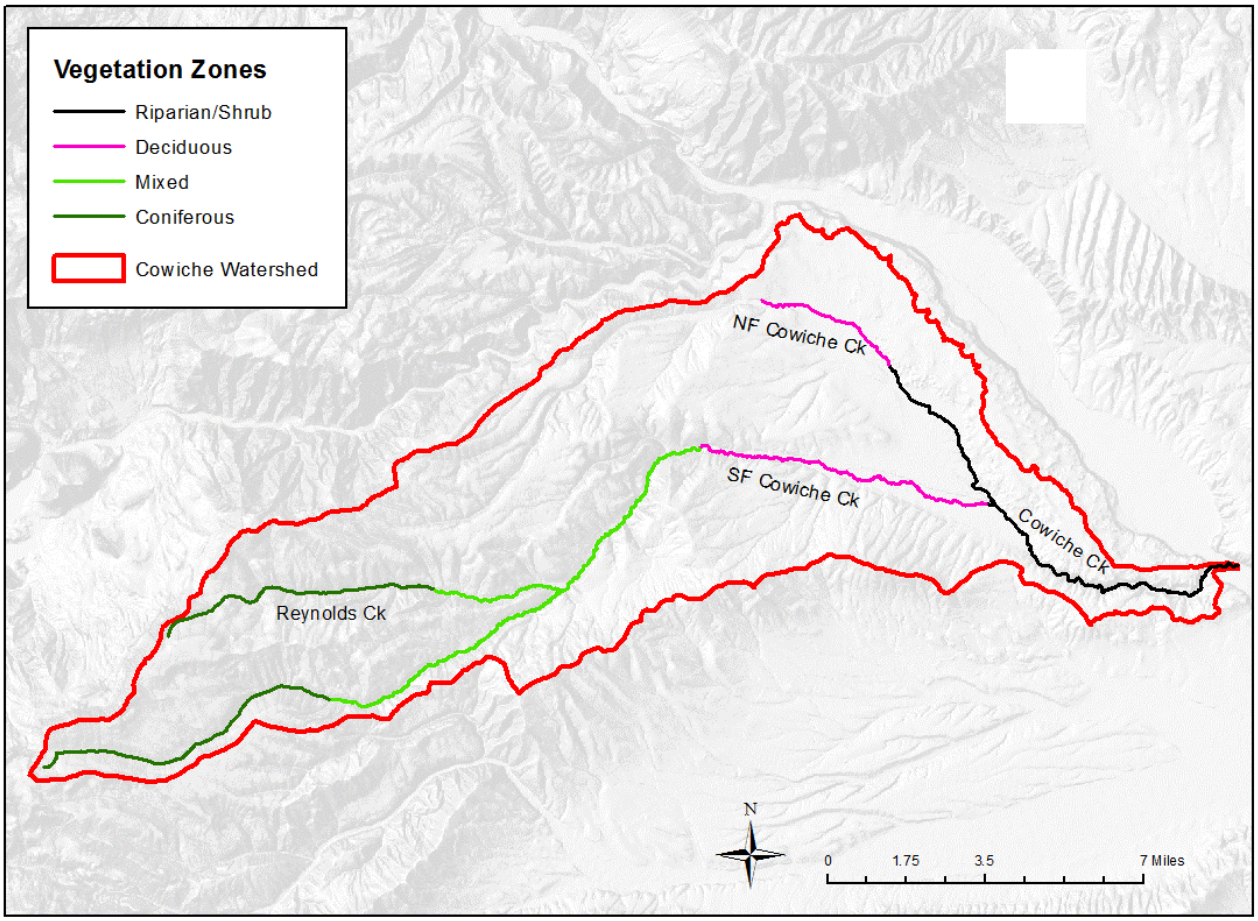

Figure 9: Map of the system potential vegetation zones in the Cowiche Creek Watershed.

Table 3: System potential riparian vegetation zones for the Cowiche Creek Watershed.

Riparian Vegetation Zones	Dominant Plants	Understory Plants	Height (m)	Density (%)	Overhang (m)
Riparian/Shrub	Willow and red osier dogwood	Rose and snowberry	5	65	0.5
Deciduous	Black cottonwood, and red osier dogwood with some Garry oak, alder, and elderberry	Willow, rose, and snowberry	18	60	1.8
Mixed*	Black cottonwood, aspen, alder, Garry oak, grand fir, Douglas fir, and ponderosa pine	Willow, vine maple, and snowberry	30	40	2.2
Coniferous	Grand fir, Douglas fir, ponderosa pine, Engelmann spruce, and western larch	Willows and alders transitioning into currant and snowberry	36	35	3.6

This study based the riparian vegetation zones from the USDA soil types. Based on those soil types, the dominant and understory plants were defined using the USDA Ecological Site/Plant Association data, USDA Forestland Productivity data, and the 2012 and 2013 vegetation data collected in the Cowiche Creek Watershed. Vegetation heights and densities in each zone are averages from the 2012 and 2013 vegetation data. Overhang (OH) is designated at 10% of the vegetation heights.

**The vegetation attributes for the Mixed vegetation zone is a compromise between the measured vegetation attributes from the 2012 and 2013 vegetation data and measured current effective shade at reference sites. The OH value are less than 10% of the height.*

Next, Ecology simulated system potential effective shade for each of the system potential vegetation zones in the Cowiche Creek Watershed using the Shade model with the vegetation characteristics listed in Table 3.

Figures 10-14 compare the simulated system potential effective shade with the simulated current effective shade. The difference between the system potential effective shade and the simulated current effective shade is the shade deficit.

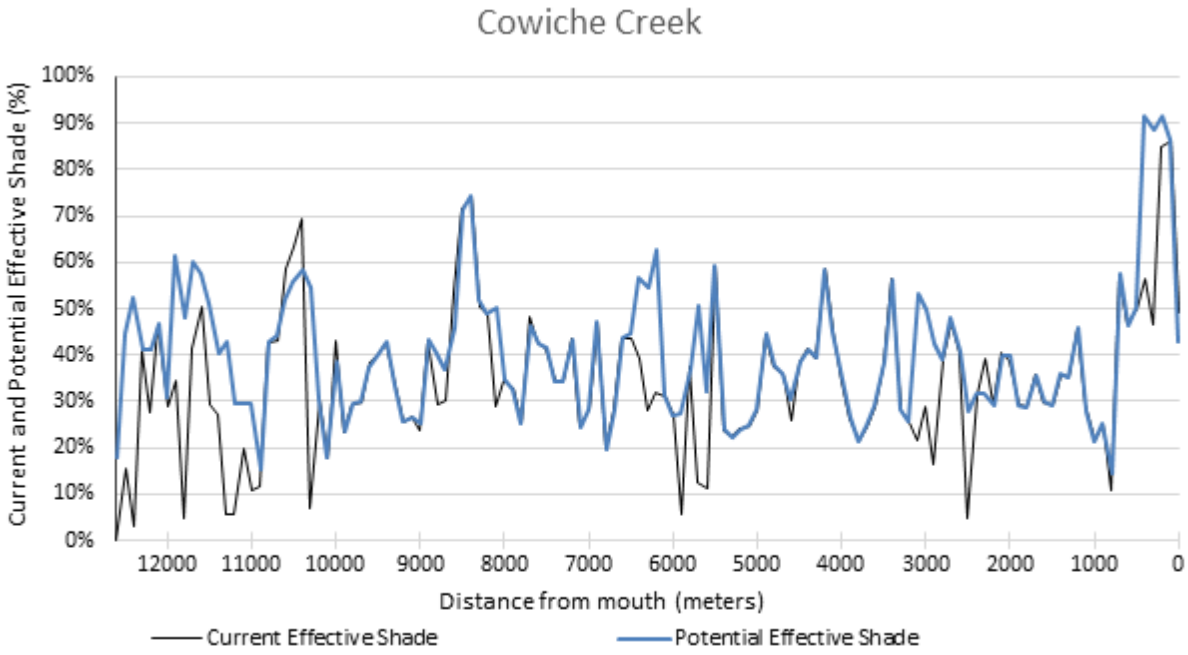

Figure 10: Comparison of the simulated system potential effective shade with the simulated current effective shade on Cowiche Creek.

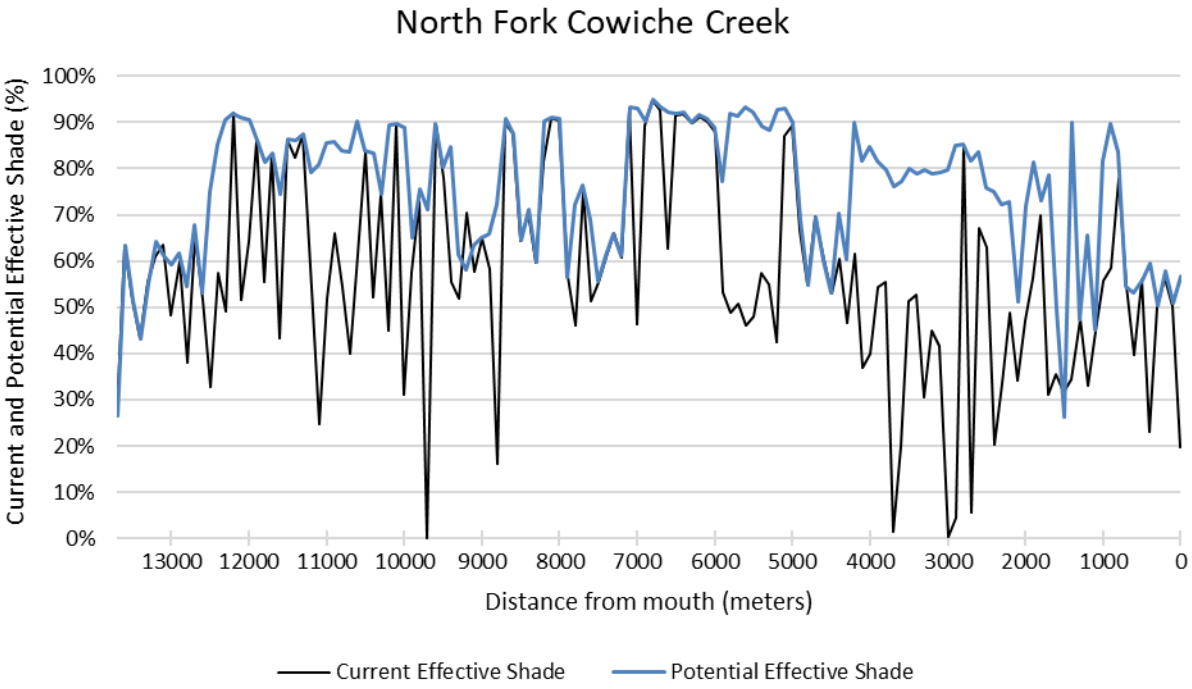

Figure 11: Comparison of the simulated system potential effective shade with the simulated current effective shade on NF Cowiche Creek.

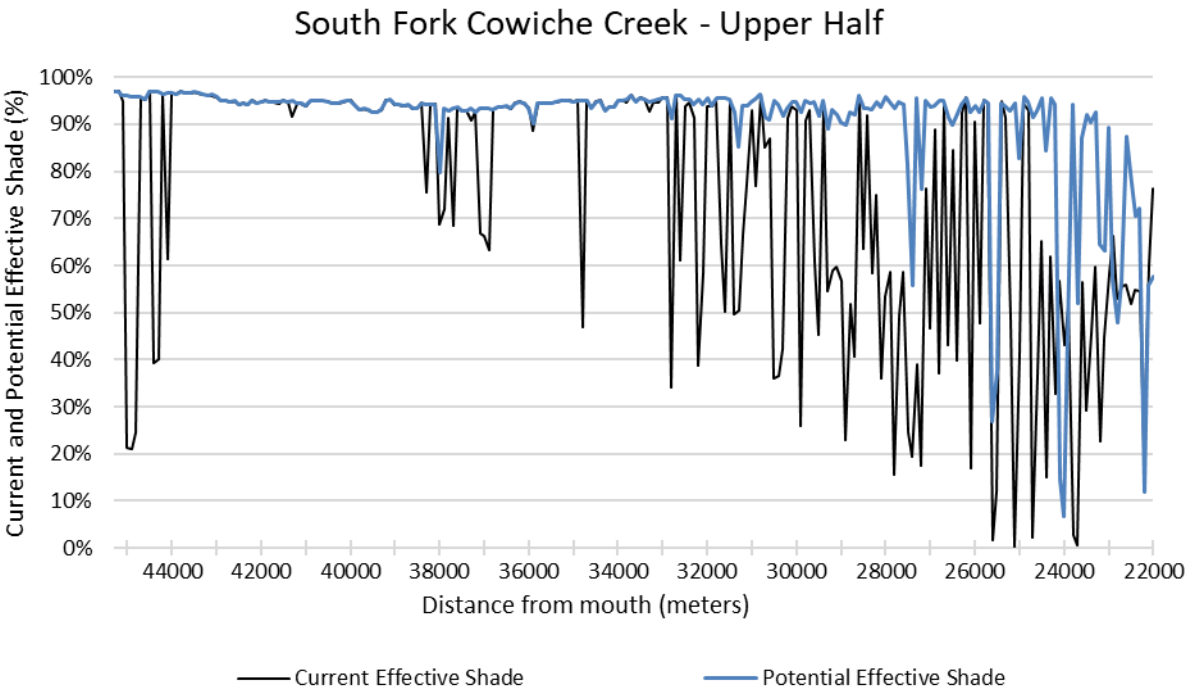

Figure 12: Comparison of the simulated system potential effective shade with the simulated current effective shade on the upper half of SF Cowiche Creek.

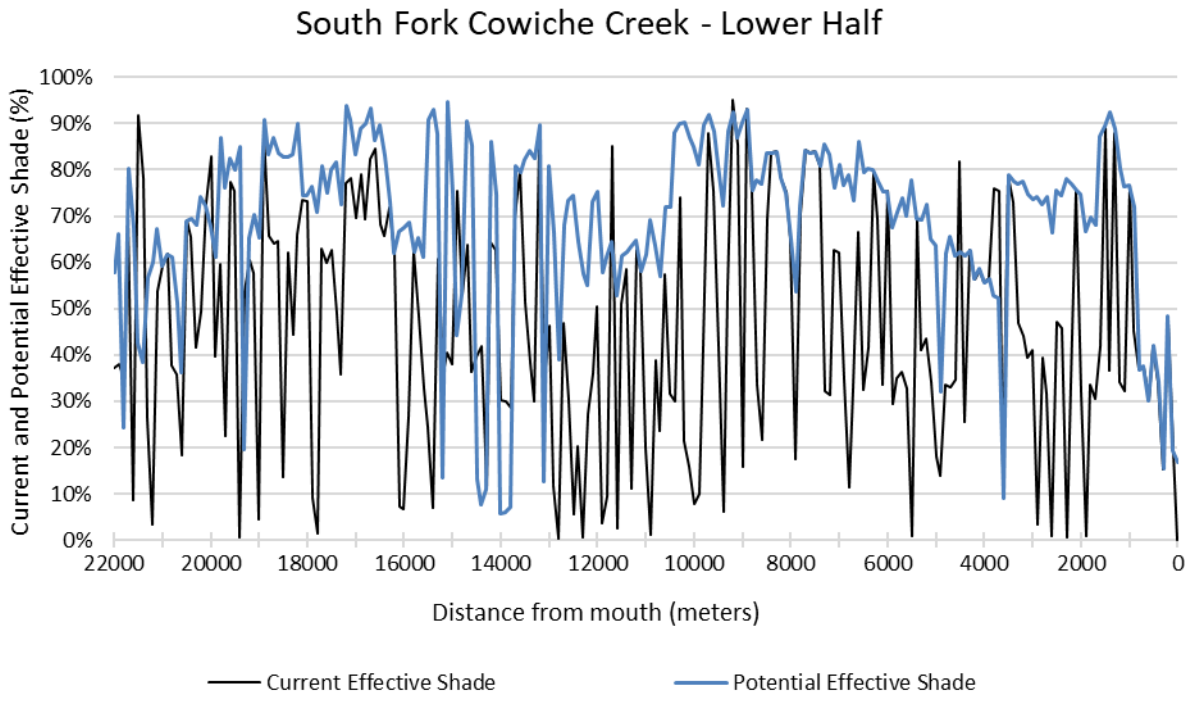

Figure 13: Comparison of the simulated system potential effective shade with the simulated current effective shade on the lower half of SF Cowiche Creek.

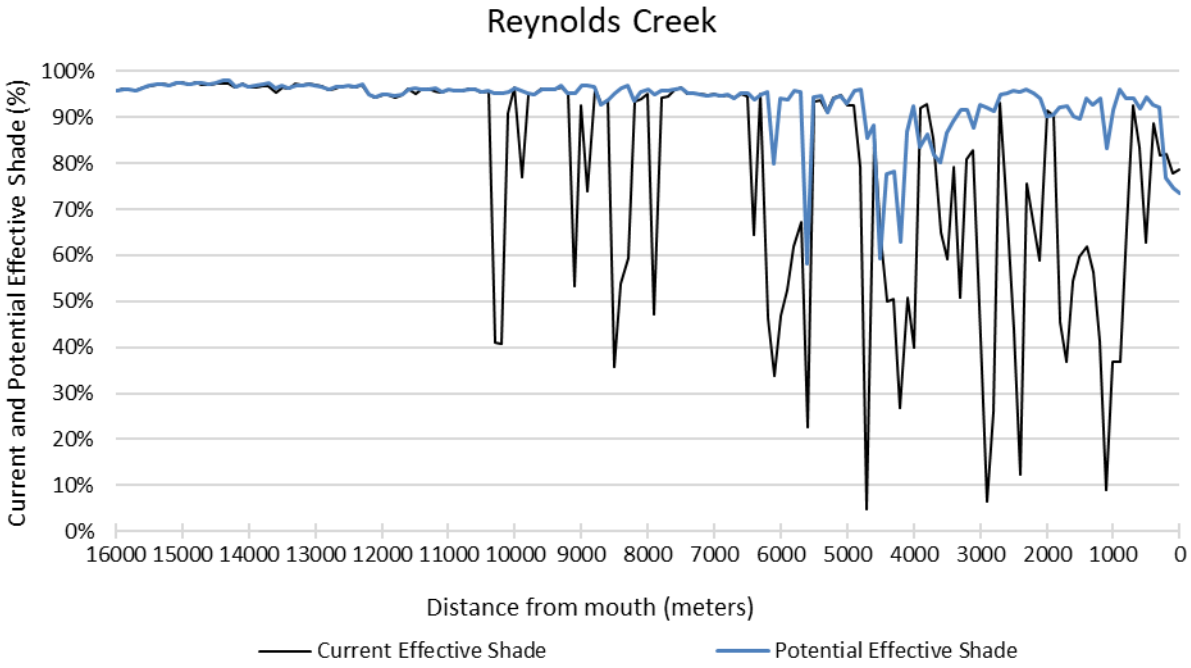

Figure 14: Comparison of the simulated system potential effective shade with the simulated current effective shade on Reynolds Creek.

Shade Deficit

The shade deficit is calculated as the difference between the 1,000-m averages of the simulated current and system potential effective shade (Appendix B, Tables B-2 to B-5). Figure 15 shows the shade deficit throughout the watershed and where more shade is needed to achieve system potential effective shade. All four creeks show that additional amounts of shade are needed to reach the system potential effective shade.

- Cowiche Creek has minimal shade deficit, meaning the shade from the current vegetation is approaching the system potential effective shade. There are still some areas needing improvement, particularly at the confluence with NF and SF Cowiche Creeks.
- Most of the shade deficit in NF Cowiche Creek is in the first 6,000m of the stream with the highest shade deficit ranging from 36-45%.
- SF Cowiche Creek has the largest shade deficit in the watershed with almost 3/4 of the stream showing a deficit. At least 30% of the creek has a deficit of 27-45%.
- Reynolds Creek shows most of its shade deficit in the first 1/3 of the stream. The highest shade deficit range, 36-45%, is found just above the mouth.

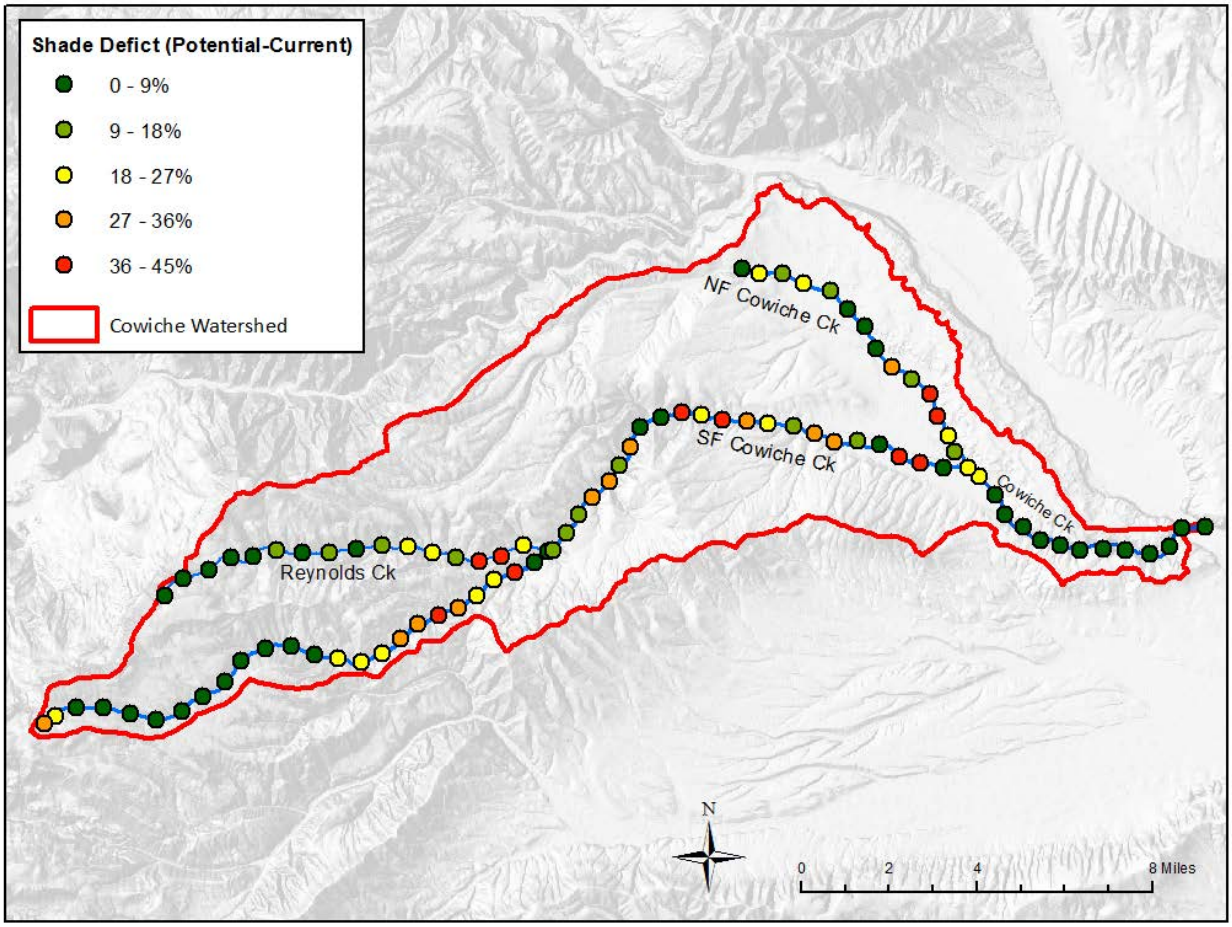

Figure 15: Shade deficit in the Cowiche Creek Watershed.
This is the amount of additional shade that is needed to reach the system potential shade in Cowiche Creek and its tributaries. The shade deficit is calculated as the difference between the 1,000-m averages of the simulated current and system potential effective shade.

Effective Shade Curves

Effective shade curves are based on the estimated relationship between shade, channel width, and stream aspect at the assumed maximum riparian vegetation condition. Those vegetation conditions are defined for each type of vegetation zone

The effective shade curves for each vegetation zone are defined in Tables C-1 to C-4 in Appendix C. Figures 16-19 represent those effective shade curves. The figures show that shade decreases as the width of the channel increases.

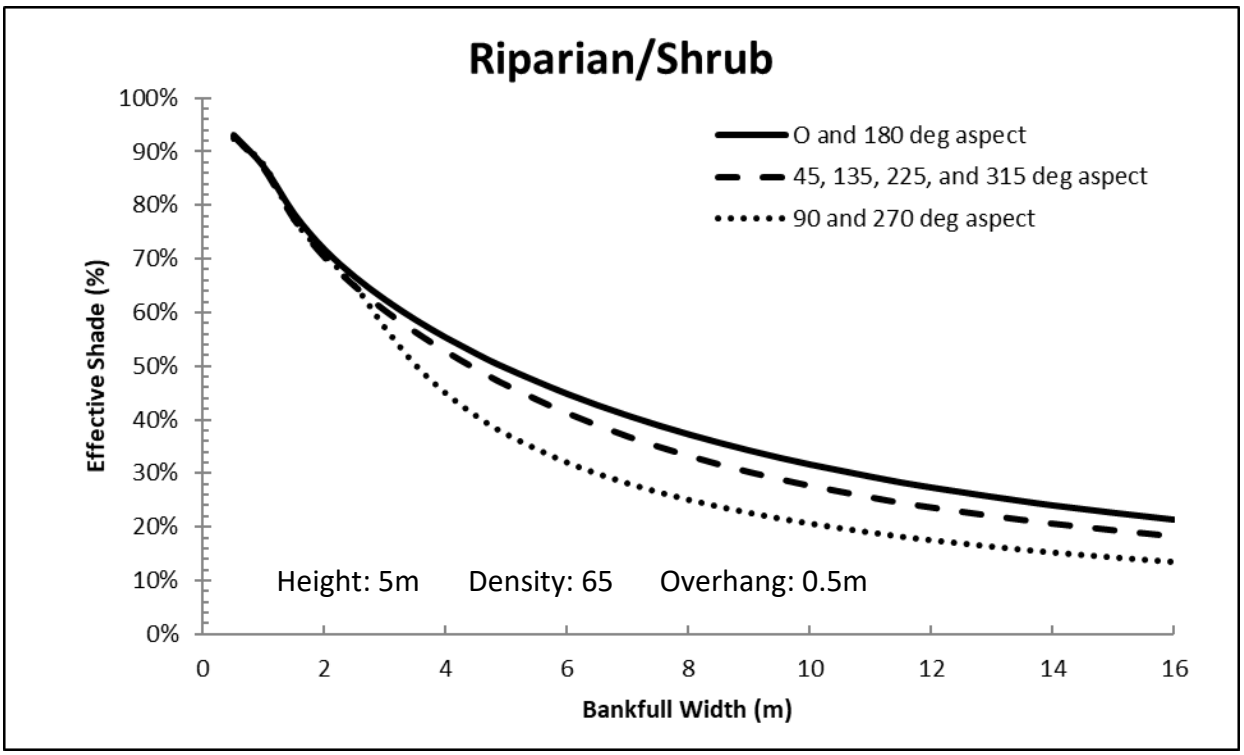

Figure 16: Potential effective shade curve for the Riparian/Shrub vegetation zone.

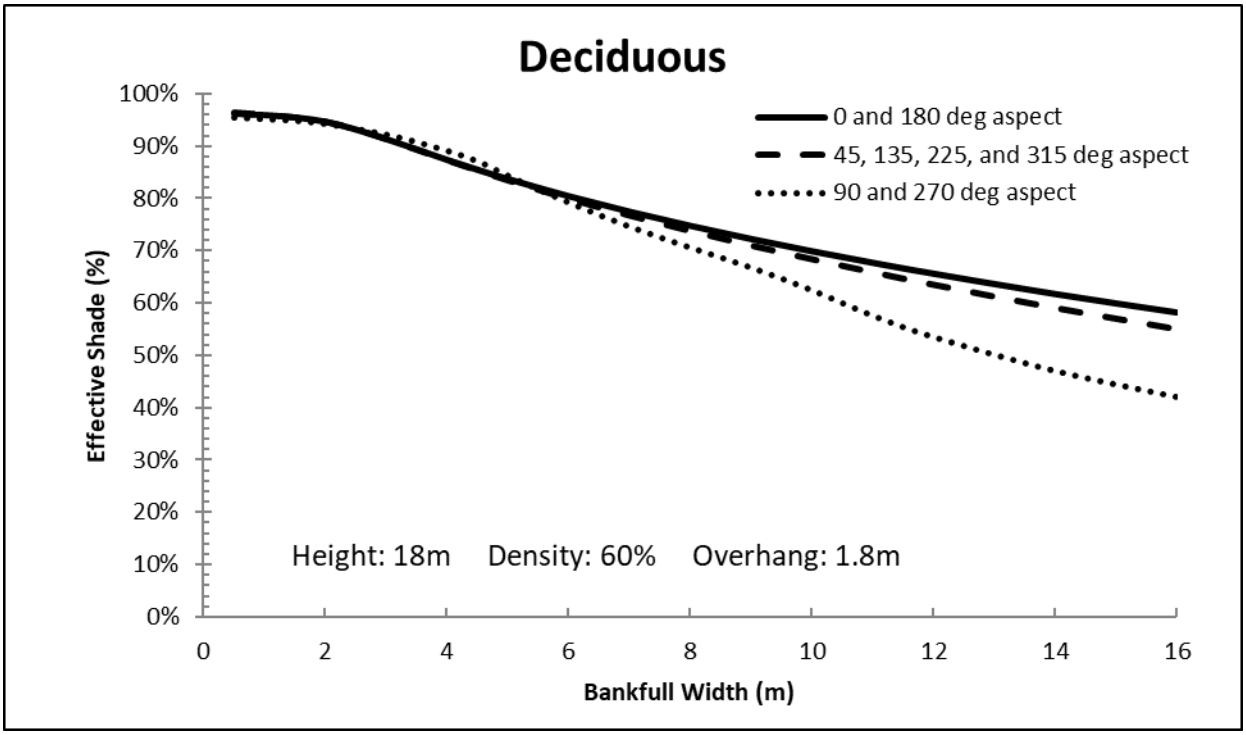

Figure 17: Potential effective shade curve for the Deciduous vegetation zone.

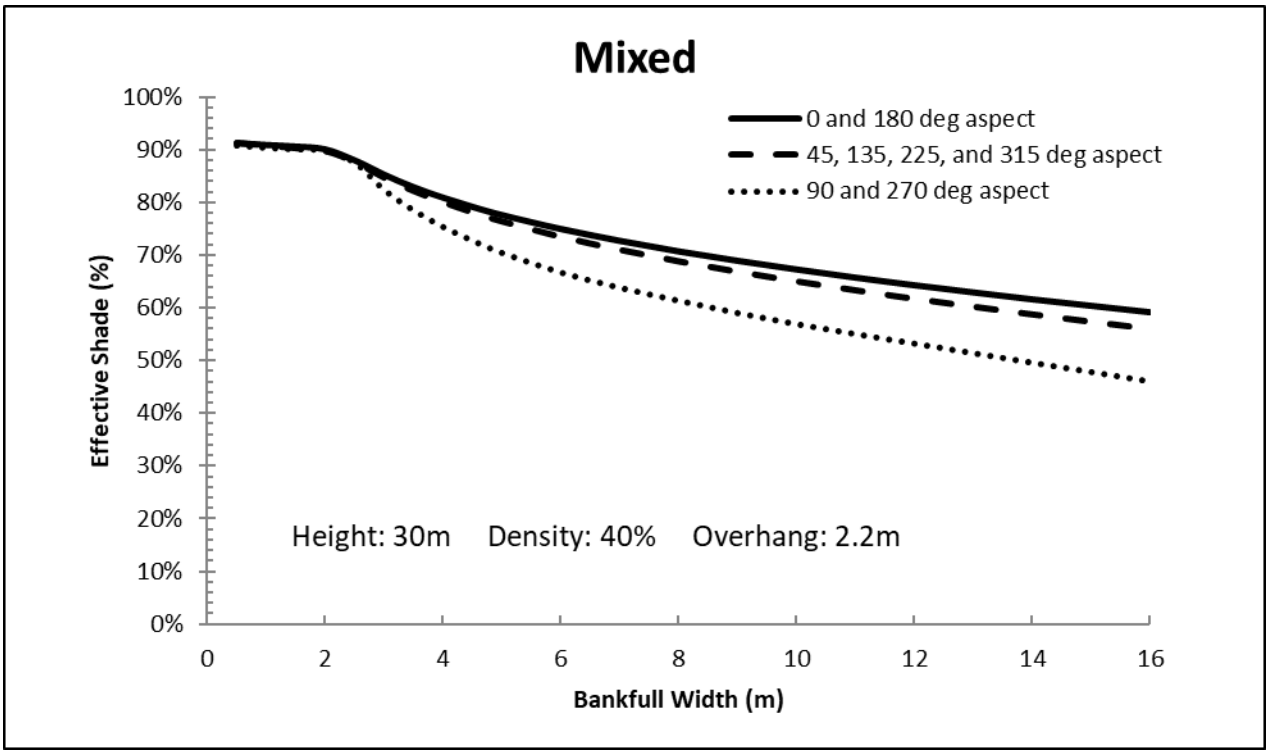

Figure 18: Potential effective shade curve for the Mixed vegetation zone.

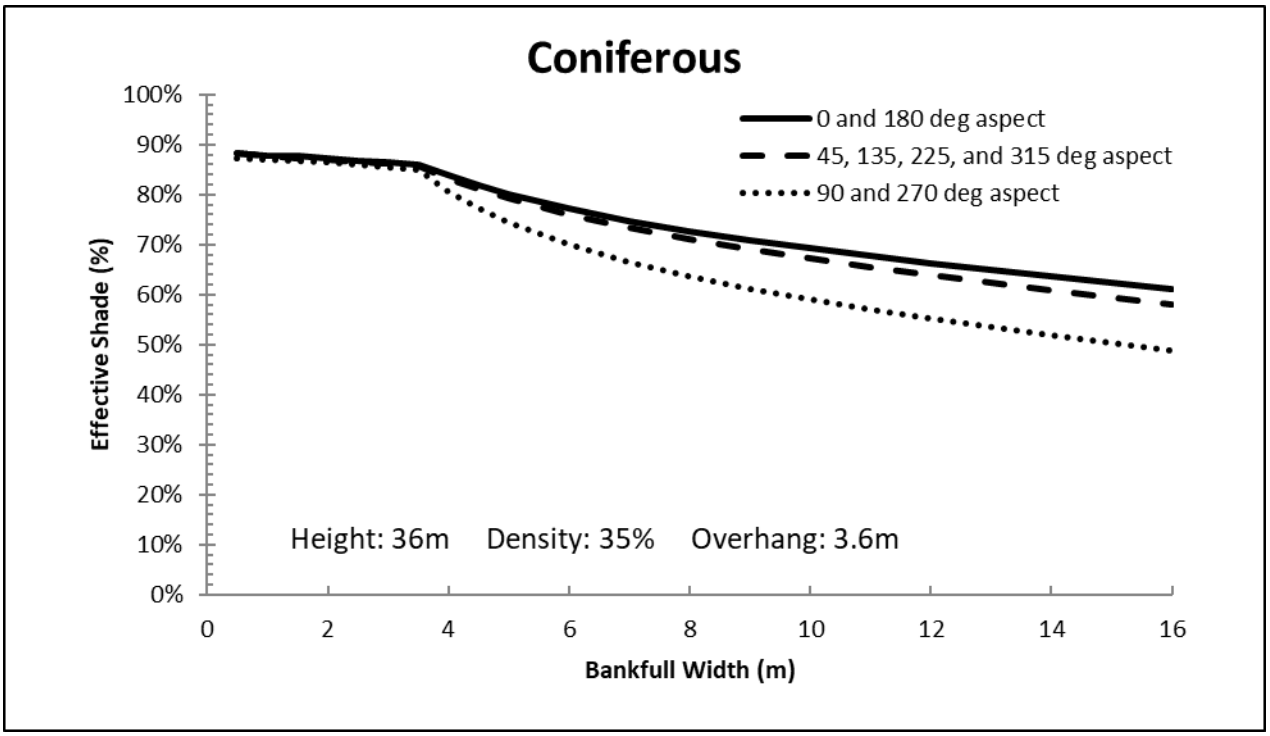

Figure 19: Potential effective shade curve for the Coniferous vegetation zone.

Cottonwood Stands

On the Yakima River, there has been a problem with the recruitment of black cottonwood (*Populus trichocarpa*) with the changes in the flow regime due to irrigation withdrawals and regulated flows (Braatne et al., 2007). In plant population ecology, recruitment refers to the process by which new individuals start a population or are added to an existing population. The most common method of recruitment is by seedlings (Eriksson et al., 2008). With the recent flow regimes on the Yakima River, regulated flows along upper reaches maintain the river near bankfull throughout the growing season, thus inundating suitable seedling recruitment sites. Downstream, irrigation withdrawals reduce the river stage, resulting in seedling establishment at low elevations that are lethally scoured by subsequent high flows (Braatne et al., 2007).

It is not known if the Cowiche Creek Watershed also suffers from the same recruitment issues, particularly from releases from either the French Canyon Reservoir on NF Cowiche or other irrigation-related return flows throughout the watershed. In order to collect some general information, Ecology conducted simple surveys in 2013 at those locations where significant stands of black cottonwoods were found.

Ecology found two sites where black cottonwood formed a significant part of the overstory, one on NF Cowiche Creek and another on SF Cowiche Creek. At these two sites, Ecology conducted a simple survey of age distribution by height class in a 60ft diameter representative circular plot (Table 4), noted canopy cover, and took hemispherical photos. A HemiView software analysis of the photos estimated the effective shade (Table 5).

- NF Cowiche Creek site is located below the French Canyon Reservoir and surrounded by irrigated apple orchards. NF Cowiche Creek often receives water releases from the reservoir, keeping a portion of the stream reach below the reservoir flowing year-round. It has a large number of cottonwoods. The majority are saplings with few mature trees. With the large number of trees in the plot, the effective shade was estimated at 76%, with a low canopy coverage.

- SF Cowiche Creek site is located above the majority of the irrigated lands and irrigation withdrawals on the creek. It exhibits a more unregulated and natural streamflow regime. There was not a large number of trees, like that found on the NF Cowiche Creek site. The SF Cowiche Creek site has a similar number of trees for each height class. The trees at this site also have a higher percentage of canopy cover than the NF Cowiche Creek site. It also produced similar effective shade percentages.

Table 4: Cottonwood height distribution.

Site ID	Site Name	Height Class Count			Estimated Canopy Coverage (%)
		Saplings (0-5ft)	Immature (5-20ft)	Mature (>20ft)	
38-NFC-07.1	NF Cowiche Ck. at Noye Rd.	49	27	6	25
38-SFC-04.2	SF Cowiche Ck. Snow Mountain Ranch 1	12	17	11	50

Table 5: HemiView effective shade for cottonwood stands.

Station Picture Name (HemiView)	Site Name	Effective Shade (%)	Year
1400 38-NFC-07.1 cotplotHV.hvs	NF Cowiche Creek	76.0	2013
1326 38-SFC-04.2 CotPlotHV.hvs	SF Cowiche Creek	67.4	2013

Conclusions

Results of this 2012/2013 study support the following conclusions:

- Riparian vegetation in the Cowiche Creek Watershed can be grouped into four vegetation zones: Riparian/Shrub, Deciduous, Mixed, and Coniferous.
    - The lower portion of the Cowiche Creek Watershed is mainly in the Riparian/Shrub or Deciduous vegetation zones.
    - The upper portions of the watershed are either in the Mixed or Coniferous vegetation zones.
- South Fork (SF) Cowiche Creek showed the greatest shade deficit in the Cowiche Creek Watershed with almost 75% of the stream showing a deficit. The areas of shade deficits are mainly (1) in the lower section of the creek that flows through agricultural lands or (2) in an area upstream, above the confluence with Reynolds Creek, where the creek flows through private property.
- North Fork (NF) Cowiche Creek showed the greatest shade deficits in the first 6,000m of the creek.
- Reynolds Creek showed its greatest shade deficits in the first 5,000m of the creek.
- Cowiche Creek has minimal shade deficits. The areas of concern are at the confluence with NF and SF Cowiche Creeks.
- Effective shade curves may be used to establish load allocations in the watershed. The shade curves, defined for each vegetation zone, show that shade decreases as the width of the channel increases.
    - Effective shade in the Coniferous vegetation zone decreases while approaching bankfull widths of 4m and greater.
    - Effective shade in the Deciduous and Mixed vegetation zones decreases after bankfull widths exceed 2m.
    - Effective shade decreases faster in the Riparian/Shrub zone after bankfull widths exceed 1m.

Recommendations

Results of this 2012/2013 study support the following recommendations:

- The establishment and maintenance of mature riparian vegetation is needed throughout the Cowiche Creek Watershed.
- The initial focus for vegetation and shade improvements should be on SF Cowiche Creek since it has the greatest shade deficit in the watershed.
- NF Cowiche Creek and Reynolds Creek show smaller areas of shade deficit. Vegetation and shade improvements should focus on the first 5,000-6,000 meters of the streams.
- Cowiche Creek shows minimal shade deficit, but improvements are still needed at its confluence with NF and SF Cowiche Creeks.
- The following applies to all four creeks discussed above:
    - The restoration or enhancement of riparian areas is needed by creating healthy riparian buffers. This is important in areas where agricultural crops, residential yards, or other land uses start near the edge of water.
    - The types of dominant and understory plants listed for each of the four vegetation zones will be useful in vegetation selections for riparian restoration projects.
    - The reduction of stream widths will be beneficial if human activities have artificially widened streams. Effective shade increases as stream widths decrease.

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Glossary, Acronyms, and Abbreviations

Glossary

Effective shade: The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of the stream by vegetation and topography.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Riparian: Relating to the banks along a natural course of water.

System potential mature riparian vegetation: That vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

System potential shade: The effective shade produced by system potential mature riparian vegetation.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector, such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
GIS	Geographic Information System software
NF	North Fork
NRCS	Natural Resource Conservation Service
SF	South Fork
TMDL	Total Maximum Daily Load (see glossary)
USDA	United States Department of Agriculture
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area

Units of Measurement

ft	feet
m	meter
W/m^2	watt per square meter

Appendices

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Appendix A. Reference Site Data Summary

Data collected at reference sites in the Cowiche Creek Watershed in 2012 and 2013 is summarized in Table A-1.

Table A-1: Summary of Vegetation Survey Data Collected at Reference Sites in the Cowiche Creek Watershed in 2012 and 2013.

						Trees			Shrubs/Tall Forbs		
Site ID	Site Name	Location (Lat/Long)	Date	Aspect (deg-rees)	Bankfull Width (ft)	Species	Cover-age (%)	Measured Heights (ft)	Species	Cover-age (%)	Mea-sured Heights (ft)
38-COW-00.0	Cowiche Ck. at mouth	N 46.62774, W 120.56954	8/21/2013	87	29	Black Cottonwood	30	103-114	Red Osier Dogwood Willow	75 25	16 10
38-COW-03.7	Cowiche Ck. Cowiche Canyon 4	N 46.61905, W 120.63163	8/15/2013	107	26				Red Osier Dogwood	20	9
38-COW-03.7 (duplicate)	Cowiche Ck. Cowiche Canyon 4	N 46.61928, W 120.63100	8/15/2013	44	32	Water Birch Black Cottonwood	50 <1	14-21 51	Reed Canary Grass Willow Sumac	10 3 3	4 10 12
38-COW-04.2	Cowiche Ck. Cowiche Canyon 3	N 46.62138, W 120.6368	8/15/2013	102	20	Water Birch Black Cottonwood Alder	5 1 1	20-22 30 8	Red Osier Dogwood Reed Canary Grass Willow Rose Sumac Chokecherry	30 30 20 3 1 1	10 4 10 5 8 8
38-COW-04.5	Cowiche Ck. Cowiche Canyon 2	N 46.62331, W 120.64220	8/15/2013	168	34	Ponderosa Pine	1	68	Willow Red Osier Dogwood Sumac Rose	15 80 2 2	14 12-14 10 6
38-COW-05.3	Cowiche Ck. Cowiche Canyon 1	N 46.62546, W 120.65392	8/15/2013	145	17	Water Birch Alder	30 5	25-29 28	Willow Red Osier Dogwood Reed Canary Grass	5 50 30	12 12 4
38-NFC-01.2	NF Cowiche Upstream of Thompson Rd Bridge	N 46.65895, W 120.69355	10/2/2012	150	20	–	–	–	Red Osier Dogwood Serviceberry Elderberry	50 10 5	23 28 4

Site ID	Site Name	Location (Lat/Long)	Date	Aspect (deg-rees)	Bankfull Width (ft)	Trees			Shrubs/Tall Forbs		
						Species	Cover-age (%)	Measured Heights (ft)	Species	Cover-age (%)	Mea-sured Heights (ft)
38-NFC-01.2 (duplicate)	NF Cowiche Upstream of Thompson Rd Bridge (duplicate)	N 46.65895, W 120.69355	10/2/2012	155	21						
38-NFC-02.6	NF Cowiche 50 ft Downstream of Cowiche WWTP Influent Pipe Crossing	N 46.67459, W120.70579	10/2/2012	166	15	–	–	–	Willow (2 species) Red Osier Dogwood Rose	45 40 90	17-21 15 4
38-NFC-04.8	NF Cowiche Ck. near old Tieton WWTP	N 46.69482, W 120.73444	9/5/2013	–	122	Black Cottonwood	20	35-66	Willow Rose Golden Currant Common Snowberry Unknown sp.	35 1 1 1 2	15-30 5 5 3 7
38-NFC-06.2	NF Cowiche Ck. at Washington St. in Tieton	N 46.70668, W 120.75745	9/5/2013	122	122	Black Cottonwood Black Hawthorn	30 5	48 12	Willow Mock Orange	25 2	33 10
38-NFC-07.1	NF Cowiche Ck. at Noye Rd.	N 46.71099, W 120.77522	9/5/2013	64	17				Willow Rose Golden Currant Common Snowberry Birch-Leaf Spirea Douglas Maple Mock Orange Antelope Bitterbrush	7 2 <1 1 1 2 <1 <1	16 8 3 4 7 8 3 6
38-NFC-07.1 (duplicate)	NF Cowiche Ck. at Noye Rd.	N 46.71115, W 120.77602	9/5/2013	114	26	Black Cottonwood Black Hawthorn Fir	40 1 5	31-42 14 36			

Site ID	Site Name	Location (Lat/Long)	Date	Aspect (deg-rees)	Bankfull Width (ft)	Trees			Shrubs/Tall Forbs		
						Species	Cover-age (%)	Measured Heights (ft)	Species	Cover-age (%)	Mea-sured Heights (ft)
38-REY-04.3	Reynolds Ck. mid-watershed	N 46.61985, W 120.97425	8/22/2013	56	10	Black Cottonwood Thin-Leaf Alder Englemann Spruce Grand Fir	20 10 8 40	101-125 18 100 78-100	Red Osier Dogwood Snowberry Douglas Maple Thimbleberry Hudson Bay Currant	3 5 10 2 2	14 3 27 4 4
38-REY-07.0	Reynolds Ck. near end of C1000 road	N 46.61512, W 121.03123	8/22/2013	94	15	Englemann Spruce Grand Fir Western Larch Subalpine Fir	8 10 5 20	117-128 87-149 125-135 48-58	Alder Hudson Bay Currant Prickly Currant Ferns	40 1 1 <1	12 3 3 1
38-REY-07.0 (duplicate)	Reynolds Ck. near end of C1000 road	N 46.61493, W 121.02852	8/22/2013	86	10						
38-SFC-00.6	SF Cowiche Ck. blw. Summitview Rd.	N 46.64694, W 120.69207	9/5/2013	73	16	Black Cottonwood Water Birch	15 5	83-95 36	Willow Red Osier Dogwood Blue Elderberry Rose Common Snowberry	10 5 10 4 <1	29 12 10-23 5 3
38-SFC-04.1	SF Cowiche Ck. Snow Mtn. Ranch 2	N 46.65839, W 120.75718	8/21/2013	23	20	Thin-Leaf Alder	15	24-32	Red Osier Dogwood Willow (4 species) Mock Orange Rose Chokecherry	40 26 3 6 <1	17 7-23 8 1 10
38-SFC-04.2	SF Cowiche Ck. Snow Mtn. Ranch 1	N 46.65866, W 120.76072	8/21/2013	67	24	Black Cottonwood Garry Oak Thin-Leaf Alder Quaking Aspen	25 5 2 4	57-72 38-44 21 31	Red Osier Dogwood Willow Mock Orange Rose Common Snowberry Chokecherry	15 4 2 2 5 2	9 14 3 7 4 15
38-SFC-04.2 (replicate)	SF Cowiche Ck. Snow Mtn. Ranch 1	N 46.6585, W 120.76009	8/21/2013	111	26						

Site ID	Site Name	Location (Lat/Long)	Date	Aspect (deg-rees)	Bankfull Width (ft)	Trees			Shrubs/Tall Forbs		
						Species	Cover-age (%)	Measured Heights (ft)	Species	Cover-age (%)	Mea-sured Heights (ft)
38-SFC-06.0	SF Cowiche Ck. Oak Ck. Wildlife Area 5	N 46.6622, W 120.79372	8/21/2013	87	18	Thin-Leaf Alder	60	21-30	Willow Red Osier Dogwood Chokecherry Douglas Maple Rose Snowberry	30 5 3 3 1 3	26-27 10 7 20 6 3
38-SFC-07.4	SF Cowiche Ck. Oak Ck. Wildlife Area 3	N 46.66568, W 120.81709	8/21/2013	79	31	Garry Oak Black Cottonwood Thin-Leaf Alder	20 15 3	36-57 59-68 17	Red Osier Dogwood Mock Orange Rose Willow Common Snowberry Ocean Spray Birch-Leaf Spirea Antelope Bitterbrush Gray Rabbitbrush	20 5 2 2 1 1 <1 <1 <1	11 9 8 18 2 9 5 4 2
38-SFC-07.8	SF Cowiche Ck. Oak Ck. Wildlife Area 1	N 46.66459, W 120.82355	8/21/2013	23	34	Garry Oak Black Cottonwood Ponderosa Pine	20 3 2	37-52 29-34 71-72	Red Osier Dogwood Willow Douglas Maple Rose Mock Orange Currant sp. Common Snowberry	40 3 1 1 1 <1 <1	12 18 9 4 9 3 3
38-SFC-07.7	SF Cowiche Ck. Oak Ck. Wildlife Area 2	N 46.66509, W 120.8223	8/21/2013	128	29	Garry Oak Black Cottonwood	20 20	34-48 54-64	Willow Red Osier Dogwood Mock Orange Common Snowberry Rose Chokecherry	10 20 2 1 1 1	31 10 8 3 8 23
38-SFC-19.1	SF Cowiche Ck. 2 mi blw Fall Ck.	N 46.58269, W 120.98042	8/14/2013	93	13	Black Cottonwood Western Larch Grand Fir	40 10 5	65-80 120-130 114-115	Red Osier Dogwood Common Snowberry Cow Parsnip	20 50 1	12 4 3
38-SFC-19.1 (replicate)	SF Cowiche Ck. 2 mi blw Fall Ck.	N 46.58269, W 120.98075	8/14/2013	100	51	Ponderosa Pine Thin-Leaf Alder	5 2	43-110 27	Douglas Maple Thimbleberry	1 1	4 3

Site ID	Site Name	Location (Lat/Long)	Date	Aspect (deg-rees)	Bankfull Width (ft)	Trees			Shrubs/Tall Forbs		
						Species	Cover-age (%)	Measured Heights (ft)	Species	Cover-age (%)	Mea-sured Heights (ft)
						Western Larch					
						Grand Fir					
						Englemann Spruce	20	69-113			
						Ponderosa Pine	25	63-70	Red Osier Dogwood	2	13
						Black	35	37-102	Willow	3	19-21
						Cottonwood	5	58-59	Prickly Currant	2	3
	SF Cowiche					Thin-Leaf Alder	1	73	Common Snowberry	1	2
	Ck. blw Fall	N 46.5881,				Cascade Mtn	1	14	Fern	1	3
38-SFC-20.6	Ck.	W 121.01192	8/14/2013	74	23	Ash	1	20	Thimbleberry	2	3
						Englemann			Red Osier Dogwood	2	10
	SF Cowiche					Spruce	35	92-121	Prickly Currant	2	3
	Ck. abv Fall	N 46.5827,				Western Larch	2	111	Hudson Bay Currant	1	4
38-SFC-21.8	Ck.	W 121.03034	8/14/2013	18	14	Grand Fir	10	39-126	Fern	4	3

Appendix B. Effective Shade and Shade Deficit

- Table B-1: HemiView effective shade data from 2004, 2012, and 2013 surveys.
- Table B-2: Cowiche Creek's shade deficit: System potential shade (avg)-current effective shade (avg)
- Table B-3: NF Cowiche Creek's shade deficit: System potential shade (avg)-current effective shade (avg)
- Table B-4: SF Cowiche Creek's shade deficit: System potential shade (avg)-current effective shade (avg)
- Table B-5: Reynold Creek's shade deficit: System potential shade (avg)-current effective shade (avg)

Table B-1: HemiView effective shade data from 2004, 2012, and 2013 surveys.

Station Picture Name (HemiView)	Stream Name	Effective Shade (%)	Year
1402 38-NFC-04.8 CHV.hvs	NF Cowiche Creek	84.1	2013
1397 38-NFC-06.2 CHV.hvs	NF Cowiche Creek	85.0	2013
1385 38-NFC-07.1 CHV.hvs	NF Cowiche Creek	88.5	2013
1394 38-NFC-07.1 DCHV.hvs	NF Cowiche Creek	67.0	2013
38-NFC-00.0.hvs	NF Cowiche Creek	54.3	2004
38-NFC-03.5.hvs	NF Cowiche Creek	95.9	2004
DSCN1224.hvs	NF Cowiche Creek	13.0	2012
DSCN1229.hvs	NF Cowiche Creek	25.2	2012
DSCN1231.hvs	NF Cowiche Creek	64.6	2012
DSCN1232.hvs	NF Cowiche Creek	52.8	2012
1354 38-COW-00.0 CHV.hvs	Cowiche Creek	42.8	2013
1297 38-COW-03.7 CHV.hvs	Cowiche Creek	28.5	2013
1302 38-COW-03.7 DCHV.hvs	Cowiche Creek	39.0	2013
1287 38-COW-04.2 CHV.hvs	Cowiche Creek	8.1	2013
1281 38-COW-04.5 CHV.hvs	Cowiche Creek	35.6	2013
1276 38-COW-05.3 CHV.hvs	Cowiche Creek	27.2	2013
38-COW-00.1.hvs	Cowiche Creek	82.0	2004
38-COW-00.5.hvs	Cowiche Creek	33.4	2004
38-COW-02.7.hvs	Cowiche Creek	48.6	2004
38-COW-05.9.hvs	Cowiche Creek	61.4	2004
COW@Trans#4.hvs	Cowiche Creek	6.3	2004
1407 38-SFC-00.6 CHV.hvs	SF Cowiche Creek	79.3	2013
1316 38-SFC-04.1 CHV.hvs	SF Cowiche Creek	77.7	2013
1307 38-SFC-04.2 CHV.hvs	SF Cowiche Creek	94.0	2013
1313 38-SFC-04.2 DCHV.hvs	SF Cowiche Creek	70.0	2013
1348 38-SFC-06.0 CHV.hvs	SF Cowiche Creek	79.4	2013
1345 38-SFC-07.2 CHV.hvs	SF Cowiche Creek	10.2	2013

Station Picture Name (HemiView)	Stream Name	Effective Shade (%)	Year
1340 38-SFC-07.4 CHV.hvs	SF Cowiche Creek	21.6	2013
1335 38-SFC-07.7 CHV.hvs	SF Cowiche Creek	43.4	2013
1330 38-SFC-07.8 CHV.hvs	SF Cowiche Creek	57.1	2013
1266 38-SFC-19.1 DCHV.hvs	SF Cowiche Creek	38.0	2013
1269 38-SFC-19.1 CHV.hvs	SF Cowiche Creek	94.1	2013
1255 38-SFC-20.6 CHV.hvs	SF Cowiche Creek	69.1	2013
1243 38-SFC-21.8 CHV.hvs	SF Cowiche Creek	77.4	2013
38-SFC-00.1.hvs	SF Cowiche Creek	84.0	2004
38-SFC-02.1.hvs	SF Cowiche Creek	78.9	2004
38-SFC-04.6.hvs	SF Cowiche Creek	89.5	2004
38-SFC-07.6.hvs	SF Cowiche Creek	57.3	2004
38-SFC-12.5.hvs	SF Cowiche Creek	64.2	2004
38-SFC-15.4.hvs	SF Cowiche Creek	67.4	2004
sfc@trans11.hvs	SF Cowiche Creek	89.7	2004
sfc@trans12.hvs	SF Cowiche Creek	53.2	2004
1380 38-REY-04.3 CHV.hvs	Reynolds Creek	71.3	2013
1359 38-REY-07.0 CHV.hvs	Reynolds Creek	96.1	2013
1374 38-REY-07.0 DCHV.hvs	Reynolds Creek	83.7	2013
1377 38-REY-08.5 CHV.hvs	Reynolds Creek	90.6	2013
38-REY-00.2.hvs	Reynolds Creek	83.9	2004
38-REY-02.0.hvs	Reynolds Creek	89.5	2004

Table B-2: Cowiche Creek's shade deficit: System potential shade (avg)-current effective shade (avg).

Distance starting from the mouth to the end (1000-meter intervals)	Current Effective Shade (average)	System Potential Shade (average)	Shade Deficit*
0	49.0%	43.1%	0.0%
0-1000	48.5%	57.3%	8.8%
1000-2000	33.7%	33.7%	0.0%
2000-3000	31.7%	38.0%	6.3%
3000-4000	30.6%	33.8%	3.2%
4000-5000	39.5%	39.9%	0.5%
5000-6000	24.8%	32.8%	8.0%
6000-7000	34.1%	41.7%	7.6%
7000-8000	36.2%	35.9%	0.0%
8000-9000	45.4%	48.9%	3.4%
9000-10000	33.2%	32.7%	0.0%
10000-11000	35.5%	40.1%	4.7%
11000-12000	24.8%	45.2%	20.4%
12000-12600	22.3%	40.7%	18.3%

*If System potential shade is less than the current effective shade, the shade deficit is equal to 0%.

Table B-3: NF Cowiche Creek's shade deficit: System potential shade (avg)-current effective shade (avg).

Distance starting from the mouth to the end (1000-meter intervals)	Current Effective Shade (average)	System Potential Shade (average)	Shade Deficit*
0	19.8%	61.2%	41.4%
0-1000	52.2%	63.7%	11.5%
1000-2000	43.1%	62.9%	19.7%
2000-3000	36.2%	76.2%	40.0%
3000-4000	39.2%	79.6%	40.3%
4000-5000	59.9%	69.8%	9.9%
5000-6000	57.7%	89.9%	32.2%
6000-7000	84.0%	92.0%	8.0%
7000-8000	65.5%	70.2%	4.7%
8000-9000	68.4%	75.8%	7.4%
9000-10000	56.5%	73.9%	17.4%
10000-11000	61.8%	85.0%	23.1%
11000-12000	66.7%	83.5%	16.8%
12000-13000	54.6%	73.0%	18.4%
13000-13700	52.1%	52.1%	0.0%

Table B-4: SF Cowiche Creek's shade deficit: System potential shade (avg)-current effective shade (avg).

Distance starting from the mouth to the end (1000-meter intervals)	Current Effective Shade (average)	System Potential Shade (average)	Shade Deficit*
0	0.0%	20.4%	20.4%
0-1000	38.3%	41.2%	2.9%
1000-2000	41.9%	79.3%	37.5%
2000-3000	31.9%	74.1%	42.3%
3000-4000	56.0%	61.2%	5.2%
4000-5000	41.8%	58.6%	16.8%
5000-6000	39.8%	71.2%	31.4%
6000-7000	46.4%	78.9%	32.5%
7000-8000	61.2%	76.8%	15.6%
8000-9000	62.9%	81.8%	18.9%
9000-10000	50.5%	85.7%	35.2%
10000-11000	31.4%	75.0%	43.6%
11000-12000	39.3%	62.1%	22.8%
12000-13000	22.5%	65.2%	42.7%
13000-14000	47.8%	53.0%	5.2%
14000-15000	48.7%	54.0%	5.3%
15000-16000	34.5%	70.5%	35.9%
16000-17000	65.9%	81.6%	15.7%
17000-18000	50.9%	79.6%	28.7%
18000-19000	54.7%	82.3%	27.7%
19000-20000	53.0%	69.4%	16.4%
20000-21000	51.1%	62.2%	11.1%
21000-22000	44.2%	56.1%	11.9%
22000-23000	56.2%	59.7%	3.4%
23000-24000	38.7%	78.2%	39.5%
24000-25000	45.8%	72.8%	27.0%
25000-26000	57.4%	80.8%	23.4%
26000-27000	64.2%	93.3%	29.1%
27000-28000	43.6%	87.4%	43.9%
28000-29000	62.4%	94.0%	31.5%
29000-30000	63.6%	92.5%	28.9%
30000-31000	68.7%	93.5%	24.9%
31000-32000	71.9%	93.8%	21.8%
32000-33000	75.6%	94.7%	19.1%
33000-34000	95.0%	95.3%	0.3%
34000-35000	89.6%	94.4%	4.8%

Distance starting from the mouth to the end (1000-meter intervals)	Current Effective Shade (average)	System Potential Shade (average)	Shade Deficit*
35000-36000	94.8%	94.8%	0.0%
36000-37000	93.3%	93.5%	0.2%
37000-38000	0.0%	0.0%	0.0%
38000-39000	87.4%	92.5%	5.2%
39000-40000	93.6%	93.6%	0.0%
40000-41000	94.7%	94.7%	0.0%
41000-42000	94.3%	94.7%	0.4%
42000-43000	94.7%	94.7%	0.0%
43000-44000	96.3%	96.3%	0.0%
44000-45000	74.3%	96.4%	22.1%
45000-45500	63.1%	96.4%	33.4%

*If System potential shade is less than the current effective shade, the shade deficit is equal to 0%.

Table B-5: Reynold Creek's shade deficit: System potential shade (avg)-current effective shade (avg).

Distance starting from the mouth to the end (1000 meter intervals)	Current Effective Shade (average)	System Potential Shade (average)	Shade Deficit*
0	79%	74%	0%
0-1000	71%	90%	19%
1000-2000	55%	91%	36%
2000-3000	50%	94%	44%
3000-4000	73%	87%	14%
4000-5000	60%	82%	23%
5000-6000	72%	91%	19%
6000-7000	81%	93%	13%
7000-8000	90%	95%	5%
8000-9000	79%	95%	17%
9000-10000	90%	96%	6%
10000-11000	84%	96%	11%
11000-12000	95%	96%	0%
12000-13000	96%	96%	0%
13000-14000	97%	97%	0%
14000-15000	97%	97%	0%
15000-16000	97%	97%	0%

*If system potential shade is less than the current effective shade, the shade deficit is equal to 0%.

Appendix C. Shade Curves

- Table C-1: Potential effective shade curve for the Riparian/Shrub vegetation category, based on bankfull width and stream aspect
- Table C-2: Potential effective shade curve for the Deciduous vegetation category, based on bankfull width and stream aspect.
- Table C-3: Potential effective shade curve for the Mixed vegetation category, based on bankfull width and stream aspect.
- Table C-4: Potential effective shade curve for the Coniferous vegetation category, based on bankfull width and stream aspect.

Table C-1: Potential effective shade curve for the Riparian/Shrub vegetation category, based on bankfull width and stream aspect.

Bankfull width (m)	Effective shade from vegetation (%) at the stream center at various stream aspects (degrees from N)			Daily average global solar short-wave radiation (W/m2*) at the stream center at various stream aspects (degrees from N)		
	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect
0.5	93%	93%	92%	19	19	21
1	87%	87%	88%	35	35	32
1.5	78%	77%	77%	59	61	61
2	72%	70%	71%	74	80	77
2.5	67%	65%	65%	88	93	93
3	62%	60%	57%	101	106	114
3.5	59%	56%	50%	109	117	133
4	55%	53%	45%	120	125	146
4.5	52%	49%	41%	128	136	157
5	50%	46%	37%	133	144	168
6	45%	41%	32%	146	157	181
7	41%	37%	28%	157	168	192
8	37%	33%	25%	168	178	200
9	34%	30%	23%	176	186	205
10	32%	28%	21%	181	192	210
11	29%	25%	19%	189	200	215
12	27%	24%	18%	194	202	218
14	24%	20%	15%	202	213	226
16	21%	18%	13%	210	218	231

*W/m2 (watt per meter square) is measure of solar irradiance, or the power per unit area received from the sun in the form of electromagnetic radiation.

Table C-2: Potential effective shade curve for the Deciduous vegetation category, based on bankfull width and stream aspect.

Bankfull width (m)	Effective shade from vegetation (%) at the stream center at various stream aspects (degrees from N)			Daily average global solar short-wave radiation (W/m2*) at the stream center at various stream aspects (degrees from N)		
	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect
0.5	96%	96%	95%	11	11	13
1	96%	96%	95%	11	11	13
1.5	96%	95%	95%	11	13	13
2	95%	95%	94%	13	13	16
2.5	93%	93%	93%	19	19	19
3	91%	91%	92%	24	24	21
3.5	89%	89%	91%	29	29	24
4	87%	87%	89%	35	35	29
4.5	86%	85%	87%	38	40	35
5	84%	83%	84%	43	46	43
6	80%	80%	79%	54	54	56
7	77%	77%	75%	62	62	67
8	75%	74%	71%	67	70	78
9	72%	71%	67%	75	78	88
10	70%	68%	62%	80	86	102
11	68%	66%	58%	86	91	113
12	66%	63%	54%	91	99	123
14	62%	59%	47%	102	110	142
16	58%	55%	42%	113	121	155

*W/m^2 (watt per meter square) is measure of solar irradiance, or the power per unit area received from the sun in the form of electromagnetic radiation.

Table C-3: Potential effective shade curve for the Mixed vegetation category, based on bankfull width and stream aspect.

Bankfull width (m)	Effective shade from vegetation (%) at the stream center at various stream aspects (degrees from N)			Daily average global solar short-wave radiation (W/m2*) at the stream center at various stream aspects (degrees from N)		
	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect
0.5	91%	91%	91%	25	25	25
1	91%	91%	90%	25	25	27
1.5	91%	90%	90%	25	27	27
2	90%	90%	90%	27	27	27
2.5	88%	88%	88%	33	33	33
3	85%	85%	82%	41	41	49
3.5	83%	82%	78%	46	49	60
4	81%	80%	75%	52	55	68
4.5	79%	78%	73%	57	60	74
5	78%	76%	70%	60	66	82
6	75%	73%	67%	68	74	90
7	73%	71%	64%	74	79	98
8	71%	69%	61%	79	85	106
9	69%	67%	59%	85	90	112
10	67%	65%	57%	90	96	117
11	66%	63%	53%	93	101	128
12	64%	62%	53%	98	104	128
14	62%	59%	50%	104	112	137
16	59%	56%	46%	112	120	147

*W/m2 (watt per meter square) is measure of solar irradiance, or the power per unit area received from the sun in the form of electromagnetic radiation.

Table C-4: Potential effective shade curve for the Coniferous vegetation category, based on bankfull width and stream aspect.

Bankfull width (m)	Effective shade from vegetation (%) at the stream center at various stream aspects (degrees from N)			Daily average global solar short-wave radiation (W/m2) at the stream center at various stream aspects (degrees from N)		
	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect
0.5	88%	88%	87%	34	34	36
1	88%	88%	87%	34	34	36
1.5	88%	87%	87%	34	36	36
2	87%	87%	86%	36	36	39
2.5	87%	87%	86%	36	36	39
3	86%	86%	86%	39	39	39
3.5	86%	86%	85%	39	39	42
4	84%	83%	81%	45	48	53
4.5	82%	81%	77%	50	53	64
5	80%	79%	74%	56	59	73
6	77%	76%	70%	64	67	84
7	75%	73%	67%	70	76	92
8	73%	71%	64%	76	81	101
9	71%	69%	61%	81	87	109
10	69%	67%	59%	87	92	115
11	68%	65%	57%	90	98	120
12	66%	64%	55%	95	101	126
14	64%	64%	52%	101	101	134
16	61%	58%	49%	109	118	143

*W/m2 (watt per meter square) is measure of solar irradiance, or the power per unit area received from the sun in the form of electromagnetic radiation.