Columbia River Cold Water Refuges Plan

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
°C	Degrees Celsius
cfs	cubic feet per second
CWR	Cold Water Refuge
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
GIS	Geographic Information System
LCEP	Lower Columbia Estuary Partnership
LCFRB	Lower Columbia Fish Recovery Board
NOAA	National Oceanic and Atmospheric Administration
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
PIT-tag	Passive Integrated Transponder-tag
SR	Snake River
SWSL	surface water source limitation
SWW	Selective Water Withdrawal
TMDL	Total Maximum Daily Load
USACE	U.S. Army Corps of Engineers
USFS	United States Forest Service
USGS	United States Geological Survey
WDFW	Washington Department of Fish and Wildlife
WQMP	Water Quality Management Plan
WRIA	Water Resource Inventory Area

EXECUTIVE SUMMARY

Placeholder text

1 INTRODUCTION

Approximately two to three million adult salmon and steelhead return from the ocean and migrate up the Columbia River each year. Those fish that migrate during the summer months when Columbia River water temperatures reach or exceed 20°C may endure adverse effects in the form of disease, stress, decreased spawning success, and lethality (EPA, 2003). To minimize their exposure to warm temperatures in the Columbia River, many salmon and steelhead temporarily move into areas of cooler water, which are called cold water refuges (CWR). In the Lower Columbia River, these CWR are primarily where cooler tributary rivers flow into the Columbia River.

This plan characterizes Columbia River water temperatures, the amount of available CWR in the Lower Columbia River (mouth to Snake River), and the extent to which salmon and steelhead use the CWR. The plan also assesses whether the amount of existing CWR is sufficient to support migrating adult salmon and steelhead and provides recommended actions to protect and restore the CWR.

1.1 REGULATORY BACKGROUND

Both the States of Oregon and Washington have established temperature water quality standards for the Lower Columbia River to protect migrating salmon and steelhead, which include a 20°C (68°F) numeric criterion[1] for limiting the maximum water temperatures. The State of Oregon also includes a narrative temperature standard that stipulates that the Lower Columbia River:

"*must have coldwater refugia that's sufficiently distributed so as to allow salmon and steelhead migration without significant adverse effects from higher water temperatures elsewhere in the water body*."

Oregon standards define coldwater refugia as

"those portions of a water body where, or times during the diel temperature cycle when, the water temperature is at least 2 degrees Celsius colder than the daily maxium temperature of the adjacent well mixed flow of the water body (OAR 340-041-0002(10))."

Under the Clean Water Act, the U.S. Environmental Protection Agency must approve (or disapprove) state water quality standards. In 2004, EPA approved the State of Oregon's temperature water quality standards for the Lower Columbia River, including the 20°C maximum numeric criterion and the cold water refugia narrative provision noted above. As part of the approval process, EPA consulted with the NOAA Fisheries per the requirements of the Endangered Species Act to ensure EPA's approval would not jeopardize the continued existence of ESA listed species.

The ESA consultation on the Oregon Lower Columbia River temperature standards noted above (among other standards) was initially completed in 2004, but was invalidated by the United States District Court of Oregon in 2012. In accordance with a court order, the ESA consultation was redone with the issuance of a new NOAA Fisheries Biological Opinion in November 2015.

[1] Oregon's 20°C numeric criterion is based on a 7 day average daily maximum. Washington's 20°C numeric criterion is based on a daily maximum.

In that Opinion, NOAA Fisheries concluded that Oregon's Lower Columbia River temperature standards are likely to jeoparize the survival and recovery of ESA listed salmon and steelhead because evidence in the record indicated that the cold water refugia narrarative standard was not being implemented and therefore may not be a functional standard and that the cold water refugia narrative standard is a critical supplement to the 20°C numeric criterion.

To avoid jeopardizing ESA listed salmon and steelhead, the NOAA Fisheries 2015 Opinion included a reasonable and prudent alternative for EPA to develop this *Columbia River Cold Water Refuges Plan*.

1.2 TYPES OF COLD WATER REFUGES

Cold water refuges are created in several ways. Tributary streams that are colder than the river they flow into provide CWR for migrating fish in the confluence area of the tributary (plume CWR) and in the lower section of the tributary (stream CWR). Fish can enter these tributary areas to reside in water temperatures cooler than the river, minimizing their heat exposure. This is the main type of CWR in the Lower Columbia River.

CWR can also be formed by inflowing groundwater colder than the river channel, including river water that submerges into the gravels then re-emerges colder than the river (referred to as hyporheic flow). CWR can occur in stratified reservoirs, where warmer surface water can be avoided by fish residing in cooler water at depth. Additionally, if a river's temperature varies throughout the day, with warmer temperatures during the daylight hours and cooler temperatures at night due to the difference in solar heating, the cooler night time conditions serve as CWR relative to the warmer daytime temperatures. These other types of CWR are minor in scope in the Lower Columbia River, and there is no evidence that they serve a significant role for salmon and steelhead in the Lower Columbia River (Appendix 12.1; High et al. 2006).

1.3 OVERVIEW OF THE COLUMBIA RIVER COLD WATER REFUGES PLAN

This plan is focused on the Lower Columbia River between the mouth and river mile 309 (Oregon-Washington border), where the Oregon cold water narrative criteria applies (***Figure 1-1***). Since the Snake River entry at river mile 325 is near the Oregon-Washington border, EPA extended some of the analyses in the plan to the Snake River. The following is a brief summary of the chapters in the plan. Chapter 2 characterizes the existing temperature conditions in the Lower Columbia River and identifies tributaries that provide CWR, including the location and size of each CWR. Chapter 3 describes how various salmon and steelhead species use CWR, including the Columbia River temperatures that trigger CWR use and the amount of salmon and steelhead that reside in CWR during the warmest time of year. Chapter 4 summarizes the adverse effects warm river temperatures have on migrating adult salmon and steelhead and the relationship of river temperature to survival rates and the loss of energy reserves. Chapter 5 assesses how much the Columbia River has warmed over the past century and the extent to which the Columbia River is predicted to continue to warm due to climate change. Chapter 6 assesses whether there is a sufficient amount of CWR to support healthy salmon and steelhead populations and attain Oregon's cold water refugia narrative criteria. Chapter 7 analyzes the watersheds of CWR tributaries and recommends actions to protect, restore, and enhance them. Chapter 8 summarizes scientific uncertainties related to CWR in the Lower Columbia River and recommends research studies to address those uncertainties. Lastly, Chapter 9 includes the plan's overall conclusions and recommendations.

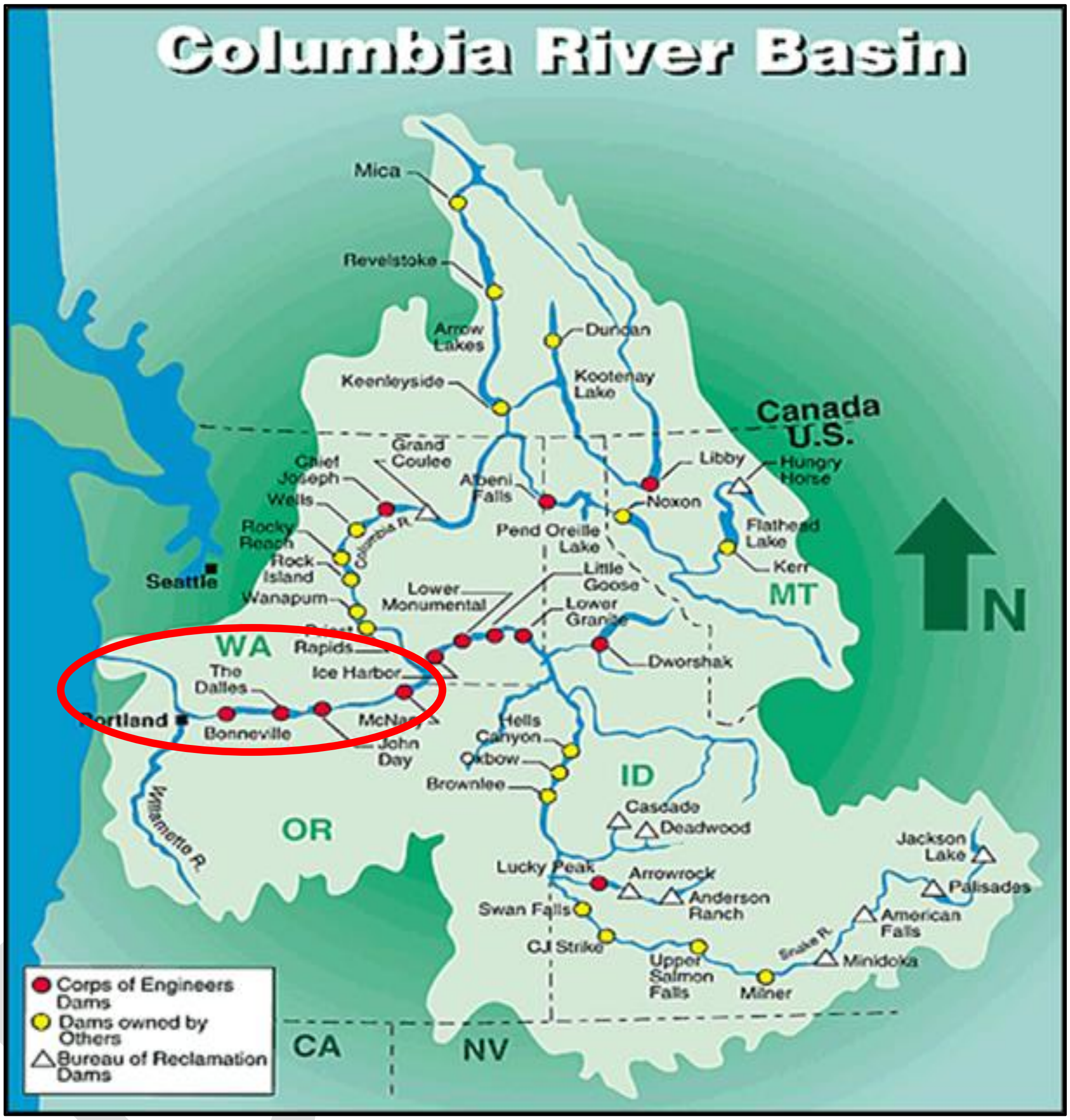

Figure 1-1 Map of the Columbia Basin, with the Columbia River Cold Water Refuges Plan scope circled in red (USACE)

2 COLD WATER REFUGES IN THE LOWER COLUMBIA RIVER

2.1 COLUMBIA RIVER TEMPERATURES

The Columbia River enters the State of Washington from Canada and warms as it moves through Washington towards the Pacific Ocean. ***Figure 2-1*** illustrates this longitudinal warming in the warm summer month of August, when river temperatures are at their seasonal peak. When the river enters Washington from Canada, average August river temperatures generally fluctuate between 17-18°C from year to year. Throughout the Lower Columbia River where the river serves as the border between Washington and Oregon, average August temperatures are between 21-22°C. This warm lower section of the river is the corridor through which all Columbia Basin salmon must begin their migration and is the focus of EPA's Cold Water Refuges Project.

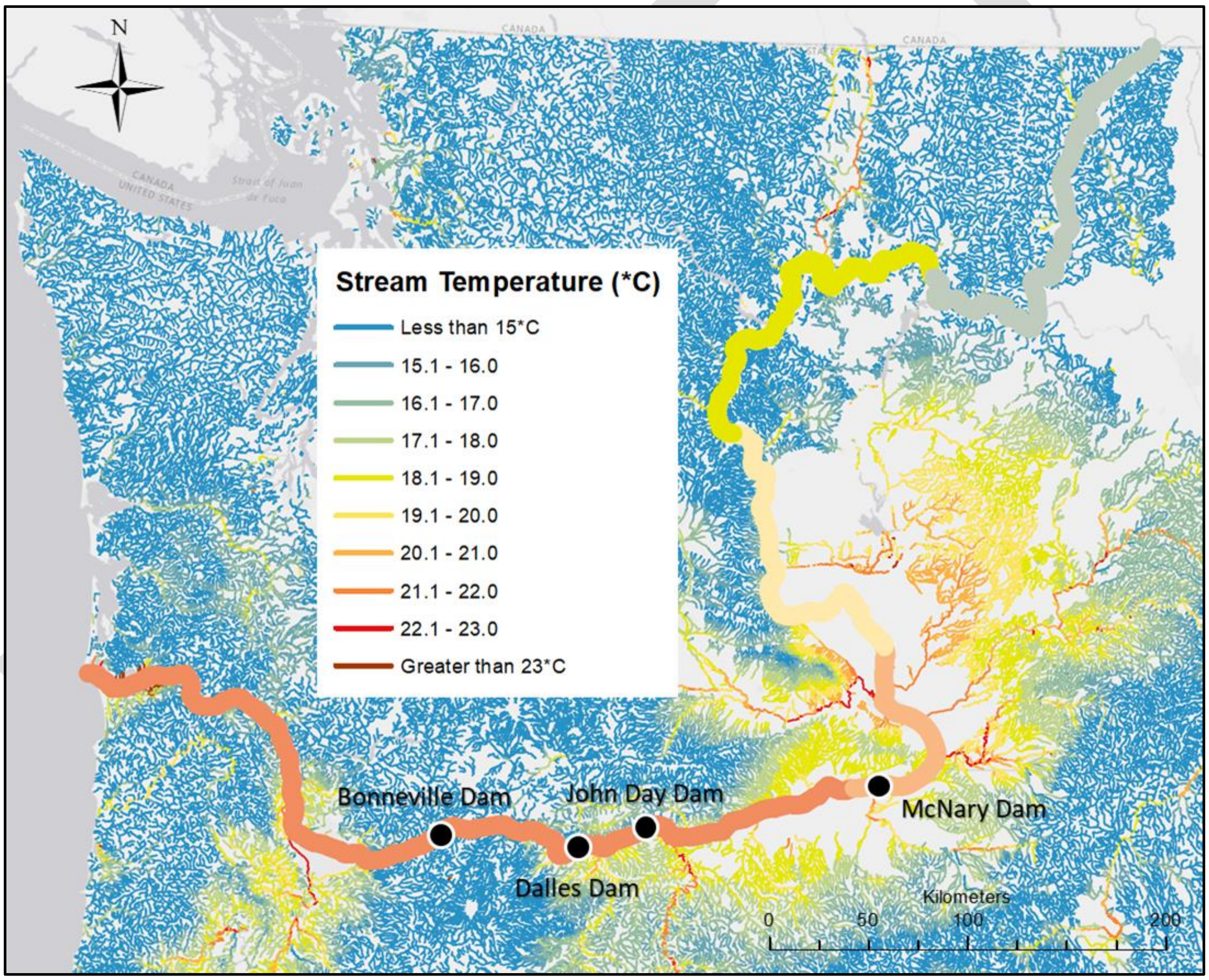

Figure 2-1 Current August mean water temperature in the Columbia River and tributaries (2011-2016) (Appendix 12.14)

Monitored Columbia River data from the four Lower Columbia River dams show the longitudinal temperature regime in the Lower Columbia River (***Figure 2-2***). Just upstream of McNary Dam, the Columbia River mixes with the Snake River, which is warmer albeit smaller than the Columbia River. At McNary Dam, the most upstream of the four Lower Columbia River dams, the average August temperature is 20.9°C. The Columbia River then warms by 0.6°C in the 80-mile pool between McNary Dam and John Day Dam. The highest average August temperatures in the Lower Columbia River and the entire Columbia River, occur near the John Day Dam, reaching 21.5°C on average in August. Temperatures decrease slightly at The Dalles Dam and the Bonneville Dam (***Figure 2-2***).

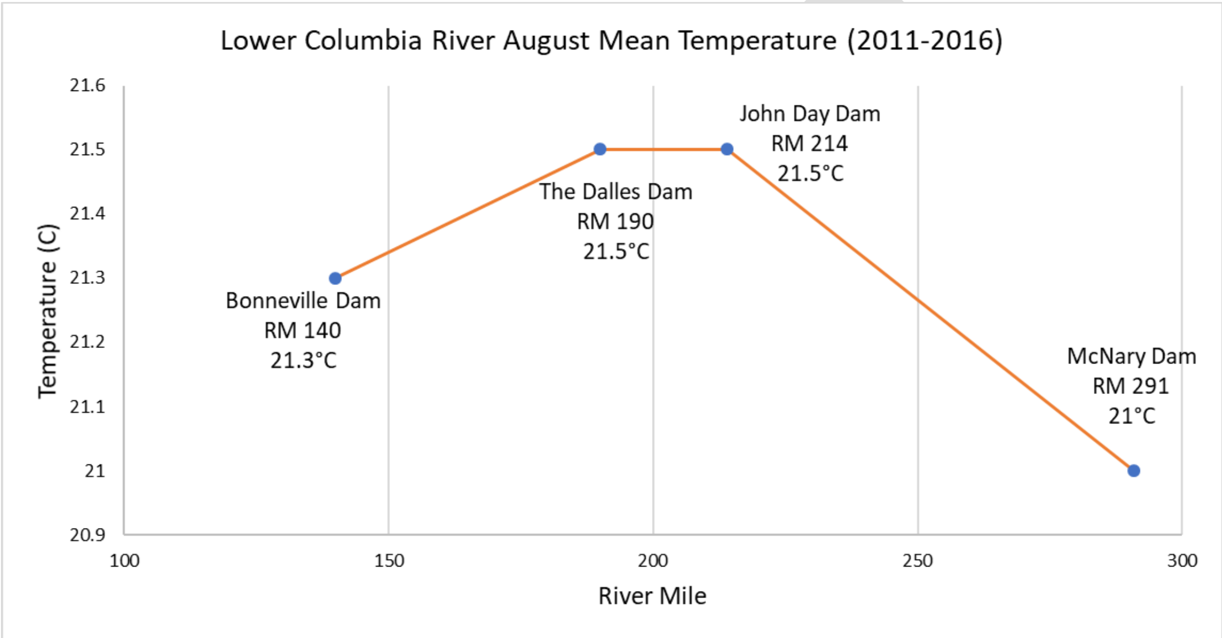

Figure 2-2 Longitudinal profile of the August mean Columbia River temperature from McNary Dam to the Bonneville Dam (DART)

Figure 2-3 illustrates the 6-year (2011-2016) daily average temperatures at the same four Columbia River dams, calculated from observed tailrace (downstream side) data. Also illustrated in ***Figure 2-3*** is the 20°C water quality standard for the Lower Columbia River, developed by both Washington and Oregon to protect migrating salmon. Daily average temperatures typically exceed 20°C for 2 months in a given summer on average throughout the Lower Columbia River, from the middle of July to the middle of September. Further, temperatures exceed 21°C for one month on average, generally the month of August, and peak close to 22°C during this time. As discussed above, temperatures at McNary Dam are slightly cooler than at the other three dams on average, and therefore the duration of exceeding these thresholds is a little less than at the other three dams.

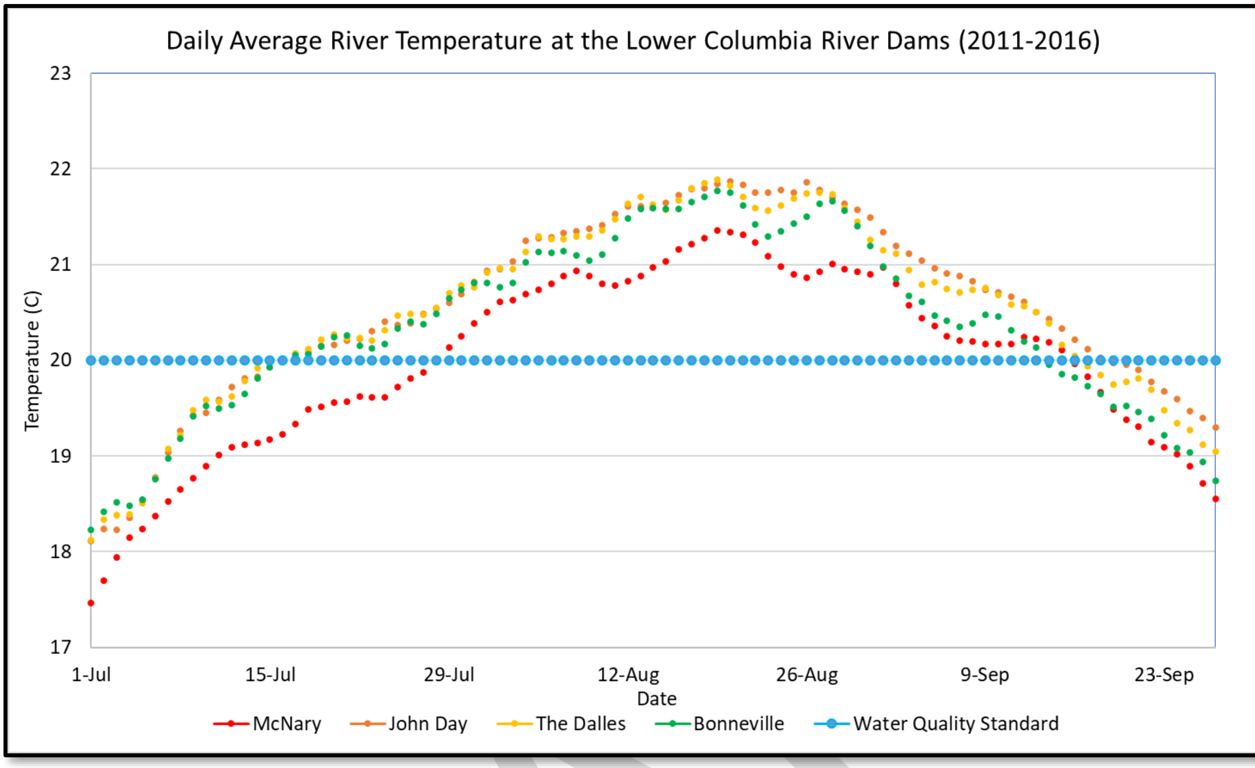

Figure 2-3 Lower Columbia River temperature from early July to mid-September, 6-year average 2011-2016 (DART)

Figure 2-1 through ***Figure 2-3*** illustrate data averaged between multiple years, which communicate patterns for typical years but does not illustrate annual variability. The temperature regime can be very different between years primarily due to weather conditions. ***Figure 2-4*** depicts observed data downstream of Bonneville Dam for 10 individual years (2009-2018) to illustrate the seasonal temperature range. The 10-year average of these Bonneville Dam daily average temperatures (thick black line) reaches 20°C in mid-July, rises to 21-22°C in August, then falls below 20°C in early September. The gray, red and blue lines illustrate the variability in the Lower Columbia River temperature regime between years, showing that magnitude, timing and duration of peak warming can vary between years.

During this 10-year timeframe, mid-July temperatures ranged from about 17.5°C in 2011 (blue line) to 22.5°C in 2015 (red line), a spread of 5°C. In mid-August, temperatures have less interannual variability, ranging from 20-22°C.

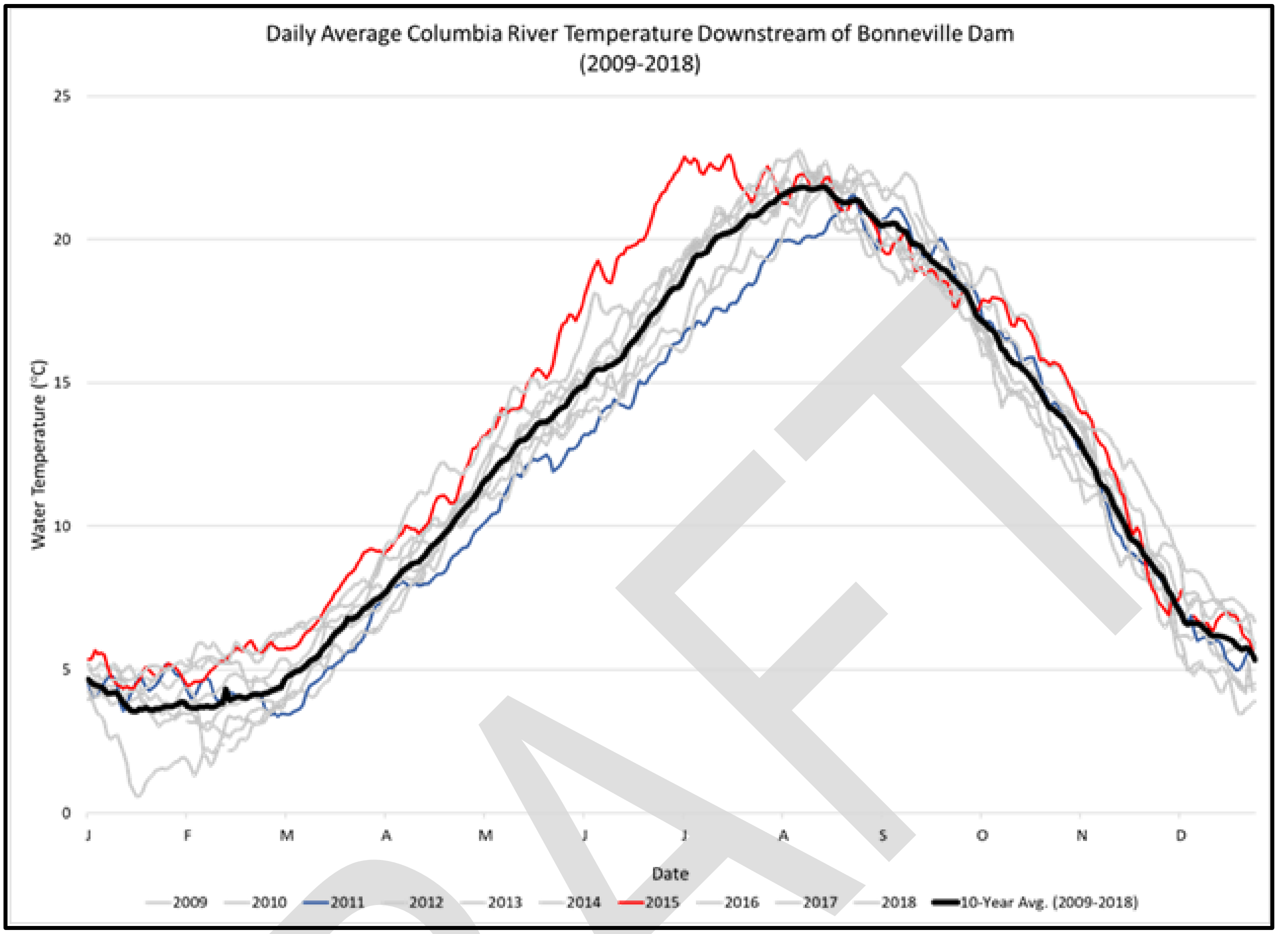

Figure 2-4 Seasonal temperature profiles downstream of Bonneville Dam, 10-year average 2009-2018 (DART)

There is little daily variation in the temperature of the Columbia River. Since the river is so large, it does not react quickly to the air temperature differential between night and day as smaller rivers and creeks tend to do. The vertical stratification of Lower Columbia River reservoirs is also minimal since they are 'run of river' reservoirs, where water moves quickly through without time to fully stratify. In contrast, reservoirs with longer residence times often exhibit a warm top layer, a thermocline, and a cold layer on the bottom (Appendix 12.1).

2.2 TRIBUTARY TEMPERATURES COMPARED TO COLUMBIA RIVER TEMPERATURES

The National Hydrography Dataset (NHD) identifies 191 tributaries that flow directly into the Columbia River between the mouth of the Columbia River and the confluence with the Snake River (Appendix 12.2). Current August mean water temperatures for these rivers were obtained from a Spatial Stream Network model developed by the U.S. Forest Service (USFS) called NorWeST. The NorWeST database houses temperature data assembled from over 100 resource agencies across the western United States, and where data are unavailable, provides modeled temperature estimates based on nearby temperature measurements and other factors

(Isaak et al. 2017). ***Figure 2-5*** illustrates these 191 tributary confluences (white dots) along with the predicted August mean temperature of the tributary.

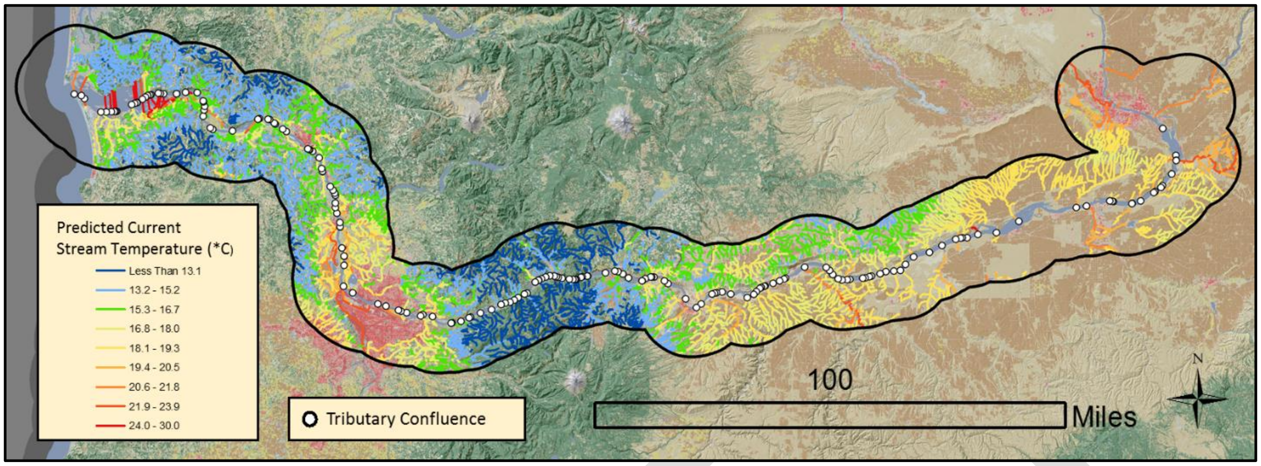

Figure 2-5 191 tributary confluences with the Lower Columbia River (white dots), with predicted stream temperatures from the NorWeST database [predicted August mean stream temperature for the 1993-2011 period]

EPA compared the predicted August mean temperature of these 191 tributaries to the August mean temperature of the Columbia River. ***Figure 2-6*** illustrates the August mean temperature difference between the Columbia River and its tributaries. Tributaries in ***Figure 2-6*** are displayed for geographical reference.

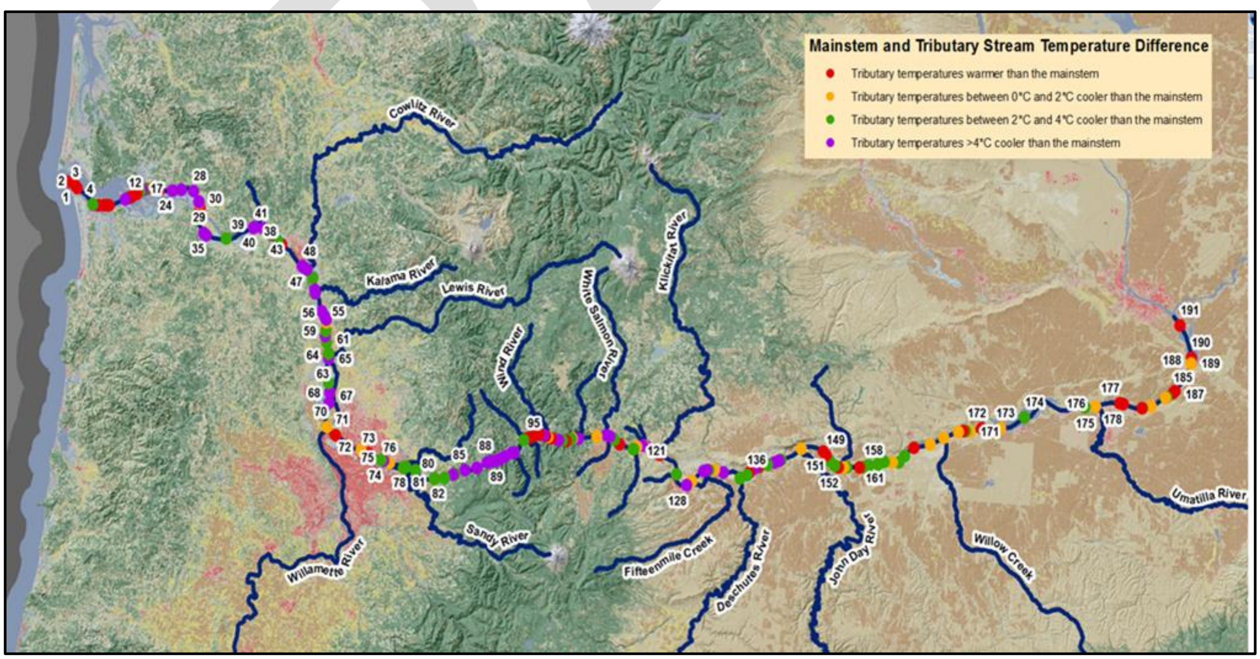

Figure 2-6 Columbia mainstem and tributary temperature difference (August mean water temperatures from USFS NorWeST)

Each of the 191 tributaries is color coded in ***Figure 2-6***, with purple identifying tributaries that are more than 4°C cooler than the Columbia River and green and yellow identifying tributaries that are between 2-4°C and 0-2°C colder than the Columbia River, respectively. Red identifies tributaries that are warmer than the Columbia River. As can be seen in the ***Figure 2-6***, most of the coolest tributaries (purple and green) are located within and downstream of the Cascade mountain range.

In addition to the temperature analysis described above, the average (1971-2000) August flows for the 191 tributaries to the Lower Columbia River were derived from the Extended Unit Runoff Method model in NHDPlusV2, a national surface water database. It is important to note that there is a very large range of stream flows within these tributaries, ranging from <1 cfs to 8591 cfs (August mean). ***Figure 2-7*** illustrates the relative flow (size of circle), tributary and Columbia River temperature (position along y-axis) and river mile (x-axis) in the Lower Columbia River. Further, this figure illustrates temperature relative to the Columbia River (color).

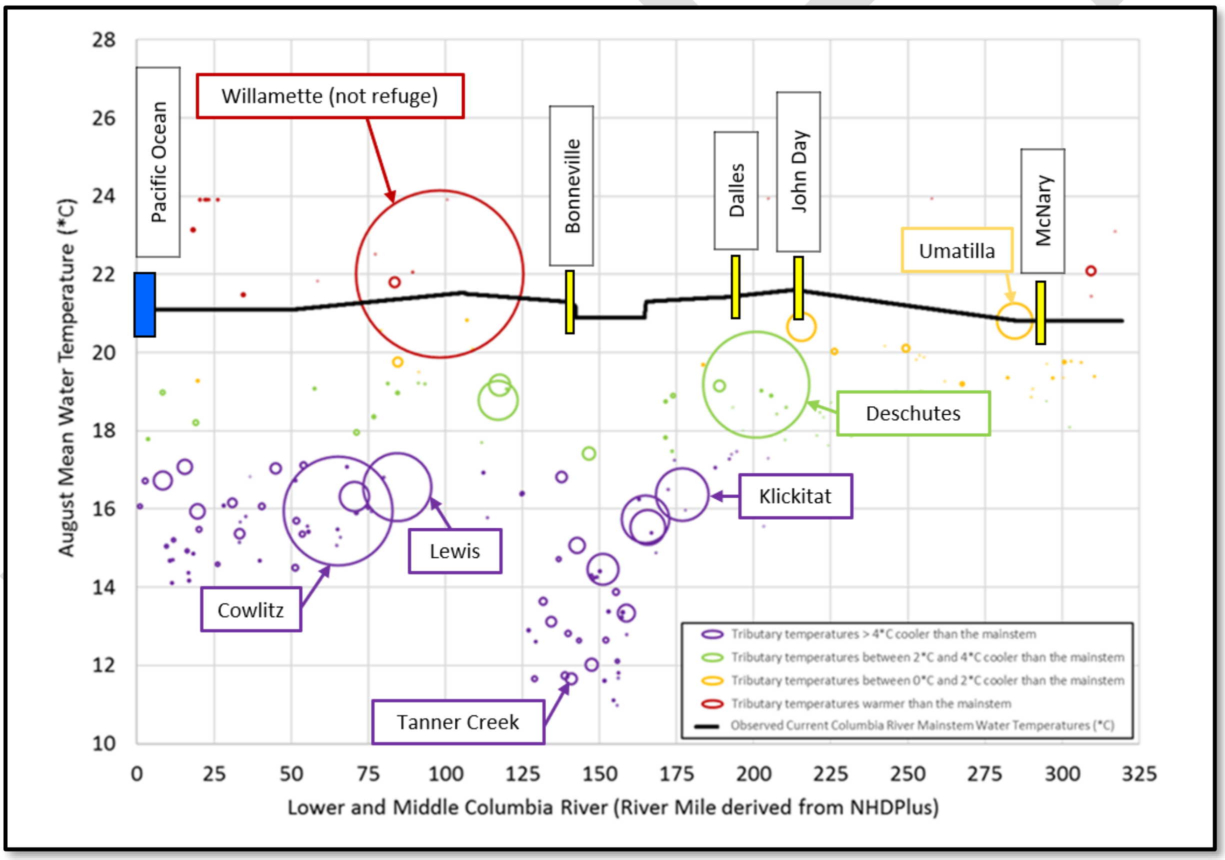

Figure 2-7 Modeled August mean stream temperatures for tributaries in the Lower Columbia River. Circle sizes illustrate relative tributary flow.

2.3 TRIBUTARIES PROVIDING COLD WATER REFUGE

Whether a tributary will provide cold water refuge is dependent upon its temperature relative to the Columbia River and the size and accessibility of its confluence area to migrating salmon and steelhead. Using the information described in section 2.2 and other information noted below, EPA conducted a screening analysis to identify tributaries that provide CWR for salmon and steelhead in the Lower Columbia River. The first screen in the analysis was based on: 1) the tributary's August mean temperature being 2°C colder than the Columbia River; and 2) the tributary's August mean flow being greater than 10 cubic feet per second (cfs). EPA used 10 cfs as an approximate minimum flow needed to form a cool water plume in the Columbia River, which would attract salmon and steelhead use (Appendix 12.3).

From this list of tributaries, EPA excluded tributaries that were inaccessible to migrating salmon and steelhead and excluded several tributaries where field flow data indicated flow was significantly less than 10 cfs. EPA added the Umatilla River to the list, because although its August mean temperature difference is less than 2°C cooler than the Columbia River, it is 2°C cooler in late August/September and is the only CWR in the John Day Reservoir, so its location is important. EPA also included two tributaries (Germany Creek and Bridal Veil Creek) on the list with August mean flows between 7-10 cfs that are especially cold. This screening approach resulted in listing 23 tributaries that currently provide CWR in the Lower Columbia River, as noted in ***Table 2-1*** (Appendix 12.3).

In ***Table 2-1*** the August mean Columbia River mainstem temperature (2005-2014) reflects data in DART from the nearest mainstem dam, the August mean tributary temperatures are from the NorWeSt model (1993-2011), and the tributary flows are either from NHD Plus (1971-2000), USGS StreamStats (Umatilla River), or, if available, USGS gage data.

Tributary Name	River Mile	August Mean Mainstem Temperature (DART)	August Mean Tributary Temperature (NorWeST)	August Mean Temperature Difference	August Mean Tributary Flow (NHD & USGS*)
		°C	°C	°C	cfs
Skamokawa Creek (WA)	30.9	21.3	16.2	-5.1	23
Mill Creek (WA)	51.3	21.3	14.5	-6.8	10
Abernethy Creek (WA)	51.7	21.3	15.7	-5.6	10
Germany Creek (WA)	53.6	21.3	15.4	-5.9	8
Cowlitz River (WA)	65.2	21.3	16.0	-5.4	3634
Kalama River (WA)	70.5	21.3	16.3	-5.0	314*
Lewis River (WA)	84.4	21.3	16.6	-4.8	1291*
Sandy River (OR)	117.1	21.3	18.8	-2.5	469
Washougal River (WA)	117.6	21.3	19.2	-2.1	107*
Bridal Veil Creek (WA)	128.9	21.3	11.7	-9.6	7
Wahkeena Creek (WA)	131.7	21.3	13.6	-7.7	15
Oneonta Creek (OR)	134.3	21.3	13.1	-8.2	29
Tanner Creek (OR)	140.9	21.3	11.7	-9.6	38
Bonneville Dam					
Eagle Creek (OR)	142.7	21.2	15.1	-6.1	72
Rock Creek (WA)	146.6	21.2	17.4	-3.8	47
Herman Creek (OR)	147.5	21.2	12.0	-9.2	45
Wind River (WA)	151.1	21.2	14.5	-6.7	293
Little White Salmon River (WA)	158.7	21.2	13.3	-7.9	88
White Salmon River (WA)	164.9	21.2	15.7	-5.5	715*
Hood River (OR)	165.7	21.4	15.5	-5.9	374
Klickitat River (WA)	176.8	21.4	16.4	-5.0	851*
The Dalles Dam					
Deschutes River (OR)	200.8	21.4	19.2	-2.2	4772*
John Day Dam					
Umatilla River[1] (OR)	284.7	20.9	20.8	-0.1	169*
McNary Dam					

[1] The Umatilla is 2°C cooler than the Columbia River in late August and September.

Table 2-1 23 tributaries providing cold water refuge in Lower Columbia River

EPA estimated the volume in cubic meters (m^3) of water that fish can rest in that is at least 2°C colder than the Columbia River for each of the 23 tributaries listed in ***Table 2-1***. The purpose of estimating the CWR volume is to compare the relative size and importance of the refuges and to assess the density of fish in CWR. EPA used a combination of monitoring and modeling techniques to estimate the volume of CWR in tributary confluence areas (plume CWR) and in the lower portion of the CWR tributaries (stream CWR) used by salmon and steelhead. As part of estimating the stream CWR volume in the lower portion of a given CWR tributary, EPA estimated how far upstream salmon or steelhead are likely to go when using it as a CWR. These 'upstream extent' estimates are based on Passive Integrative Transponder-tag (PIT-tag) and radio tag information, discussions with field biologists, stream depth measurements, satellite images, and field observations (Appendix 12.4). To estimate the volume of the plume extending into the Columbia River that remained 2°C colder than the Columbia River itself (plume CWR), EPA used a Cormix plume model or in some cases (Herman Creek Cove, Little White Salmon (Drano Lake), and the Wind River delta) took direct measures of embayment areas to calculate the volumes (Appendix 12.5 through 12.11). The 23 tributaries and their associated plume CWR and stream CWR are listed in ***Table 2-2***.

Tributary Name	River Mile	August Mean Mainstem Temperature (DART)	August Mean Tributary Temperature (NorWeST)	August Mean Temperature Difference	August Mean Tributary Flow (NHD & USGS*)	Plume CWR Volume (> 2°C Δ)	Stream CWR Volume (> 2°C Δ)	Total CWR Volume (> 2°C Δ)
		°C	°C	°C	cfs	m^3	m^3	m^3
Skamokawa Creek (WA)	30.9	21.3	16.2	-5.1	23	450	1,033	1,483
Mill Creek (WA)	51.3	21.3	14.5	-6.8	10	110	446	556
Abernethy Creek (WA)	51.7	21.3	15.7	-5.6	10	81	806	887
Germany Creek (WA)	53.6	21.3	15.4	-5.9	8	72	446	518
Cowlitz River (WA)	65.2	21.3	16.0	-5.4	3634	870,000	684,230	1,554,230
Kalama River (WA)	70.5	21.3	16.3	-5.0	314*	14,000	27,820	41,820
Lewis River (WA)	84.4	21.3	16.6	-4.8	1291*	120,000	493,455	613,455
Sandy River (OR)	117.1	21.3	18.8	-2.5	469	9,900	22,015	31,915
Washougal River[1] (WA)	117.6	21.3	19.2	-2.1	107*	740	32,563	33,303
Bridal Veil Creek (WA)	128.9	21.3	11.7	-9.6	7	120	0	120
Wahkeena Creek (WA)	131.7	21.3	13.6	-7.7	15	220	0	220
Oneonta Creek (OR)	134.3	21.3	13.1	-8.2	29	820	54	874
Tanner Creek (OR)	140.9	21.3	11.7	-9.6	38	1,300	413	1,713
Bonneville Dam								
Eagle Creek (OR)	142.7	21.2	15.1	-6.1	72	2,100	888	2,988
Rock Creek[1] (WA)	146.6	21.2	17.4	-3.8	47	530	1,178	1,708
Herman Creek (OR)	147.5	21.2	12.0	-9.2	45	168,000	1,698	169,698
Wind River (WA)	151.1	21.2	14.5	-6.7	293	60,800	44,420	105,220
Little White Salmon River (WA)	158.7	21.2	13.3	-7.9	88	1,097,000	4,126	1,101,126
White Salmon River (WA)	164.9	21.2	15.7	-5.5	715*	72,000	81,529	153,529
Hood River (OR)	165.7	21.4	15.5	-5.9	374	28,000	0	28,000
Klickitat River (WA)	176.8	21.4	16.4	-5.0	851*	73,000	149,029	222,029
The Dalles Dam								
Deschutes River (OR)	200.8	21.4	19.2	-2.2	4772*	300,000	580,124	880,124
John Day Dam								
Umatilla River[1] (OR)	284.7	20.9	20.8	-0.1	169*	0	46,299	46,299
McNary Dam								

[1] Only provide intermittent cold water refugia; CWR volume represents volume when river is greater than 2°C colder than Columbia River.

Table 2-2 Estimates for the volume of water in tributary confluence areas that is more than 2°C cooler than the Columbia River

2.4 TWELVE PRIMARY COLD WATER REFUGES

Of the 23 tributaries in ***Table 2-1*** and ***Table 2-2***, EPA identified 12 as important primary CWR areas based on CWR volume, stream temperatures, field observations, and documented or presumed use by salmon and steelhead (Appendix 12.5). The 12 primary CWR are bolded in ***Table 2-3*** and displayed in ***Figure 2-8***. In both ***Table 2-3*** and ***Figure 2-8***, primary CWR tributaries that are >4°C cooler than the Columbia are highlighted in purple, and primary CWR tributaries with temperatures 2-4°C cooler than the Columbia are highlighted in green.

The 12 primary tributaries constitute 97% of the total CWR volume in the Lower Columbia River, are easily accessible, are sufficiently deep to provide cover, and have documented or presumed use by migrating salmon and steelhead. The other 11 non-primary CWR tributaries have small CWR volume (less than 2,000 m^3), have substantial periods of time when the tributary is less than 2°C cooler or even warmer than the Columbia River, and/or are shallow and exposed. Additionally, the extent of use by salmon and steelhead in these 11 non-primary CWR tributaries is unknown and likely is limited due to one or more of the characteristics noted above (Appendix 12.5).

Tributary Name	River Mile	August Mean Mainstem Temperature (DART)	August Mean Tributary Temperature (NorWeST)	August Mean Temperature Difference	August Mean Tributary Flow (NHD & USGS*)	Plume CWR Volume (> 2°C Δ)	Stream CWR Volume (> 2°C Δ)	Total CWR Volume (> 2°C Δ)
		°C	°C	°C	cfs	m^3	m^3	m^3
Skamokawa Creek (WA)	30.9	21.3	16.2	-5.1	23	450	1,033	1,483
Mill Creek (WA)	51.3	21.3	14.5	-6.8	10	110	446	556
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Lewis River (WA)	84.4	21.3	16.6	-4.8	1291*	120,000	493,455	613,455
Sandy River (OR)	117.1	21.3	18.8	-2.5	469	9,900	22,015	31,915
Washougal River[1] (WA)	117.6	21.3	19.2	-2.1	107*	740	32,563	33,303
Bridal Veil Creek (WA)	128.9	21.3	11.7	-9.6	7	120	0	120
Wahkeena Creek (WA)	131.7	21.3	13.6	-7.7	15	220	0	220
Oneonta Creek (OR)	134.3	21.3	13.1	-8.2	29	820	54	874
Tanner Creek (OR)	140.9	21.3	11.7	-9.6	38	1,300	413	1,713
Eagle Creek (OR)	142.7	21.2	15.1	-6.1	72	2,100	888	2,988
Rock Creek[1] (WA)	146.6	21.2	17.4	-3.8	47	530	1,178	1,708
Herman Creek (OR)	147.5	21.2	12.0	-9.2	45	168,000	1,698	169,698
Wind River (WA)	151.1	21.2	14.5	-6.7	293	60,800	44,420	105,220
Little White Salmon River (WA)	158.7	21.2	13.3	-7.9	88	1,097,000	4,126	1,101,126
White Salmon River (WA)	164.9	21.2	15.7	-5.5	715*	72,000	81,529	153,529
Hood River (OR)	165.7	21.4	15.5	-5.9	374	28,000	0	28,000
Klickitat River (WA)	176.8	21.4	16.4	-5.0	851*	73,000	149,029	222,029
Deschutes River (OR)	200.8	21.4	19.2	-2.2	4772*	300,000	580,124	880,124
Umatilla River[1] (OR)	284.7	20.9	20.8	-0.1	169*	0	46,299	46,299

[1] Only provide intermittent cold water refugia; CWR volume represents volume when river is greater than 2°C colder than Columbia River.
[2] Tidally influenced and may be inaccessible during low tides.

Table 2-3 Twelve primary CWR tributaries (highlighted in bold and color)

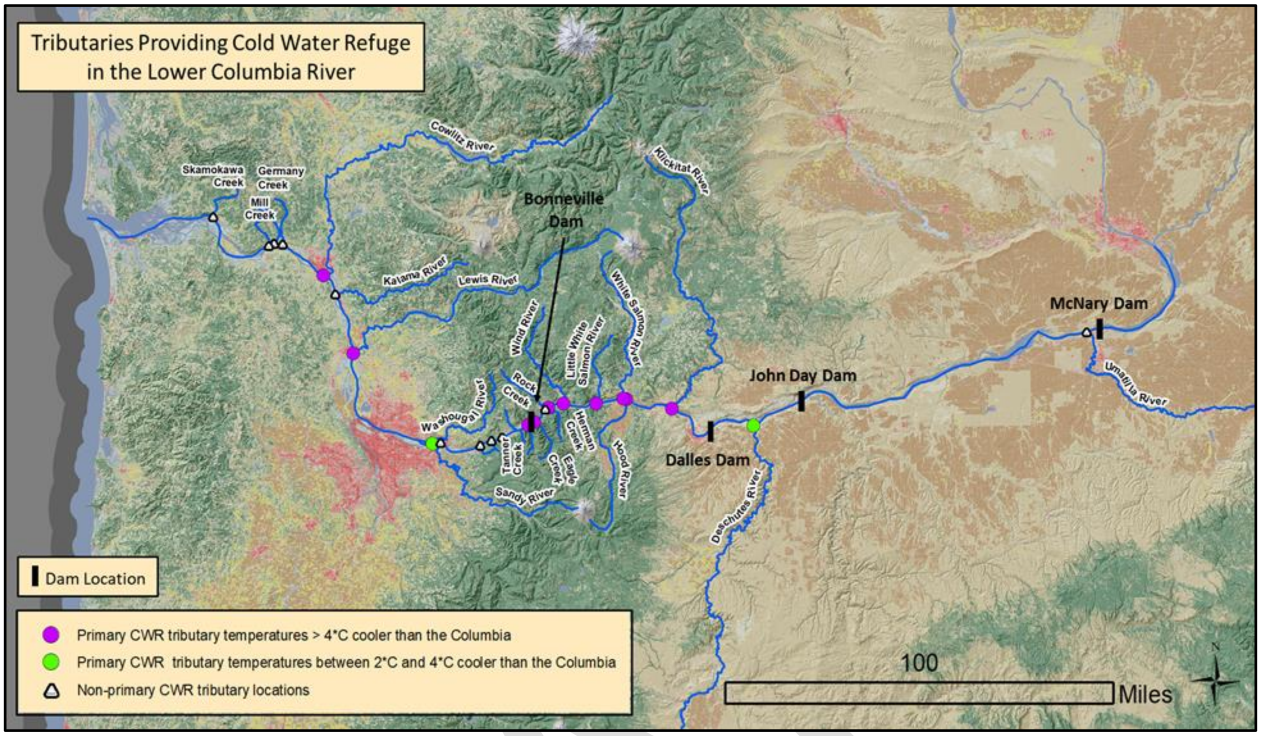


Figure 2-8 Twelve primary cold water refuge tributaries (purple and green) to the Lower Columbia River as well as the 11 non-primary cold water refuge tributaries (white)

Four of the 12 primary CWR tributaries are below Bonneville Dam, seven are between the Bonneville Dam and The Dalles Dam, and only one, the Deschutes River, is upstream of The Dalles Dam. The two largest CWR are the Cowlitz River confluence area CWR and the Little White Salmon River CWR, which drains into Drano Lake prior to entering the Columbia River. The total volume of all 23 CWR is roughly 5 million cubic meters, which is equivalent to 2,000 Olympic-sized swimming pools. The 12 primary CWR constitute an estimated 97% of the total CWR volume in the Lower Columbia River.

Each of the 12 primary CWR tributaries is shown in ***Figure 2-9*** through ***Figure 2-20***. On each figure is a yellow pin showing the 'upstream extent,' which signifies how far upstream EPA estimates salmon and steelhead will go up the tributary when using it as a CWR (Appendix 12.4). Each figure also includes the average August-September temperature profile of both the Columbia River (black) and the tributary (purple) to illustrate the difference in water temperatures over time between the two (see Appendix 12.12 for larger temperature profile graphics). Some of the figures include a pink pin, which is the location of a PIT-tag antenna that records fish with inserted PIT-tags if they swim past the receiver.

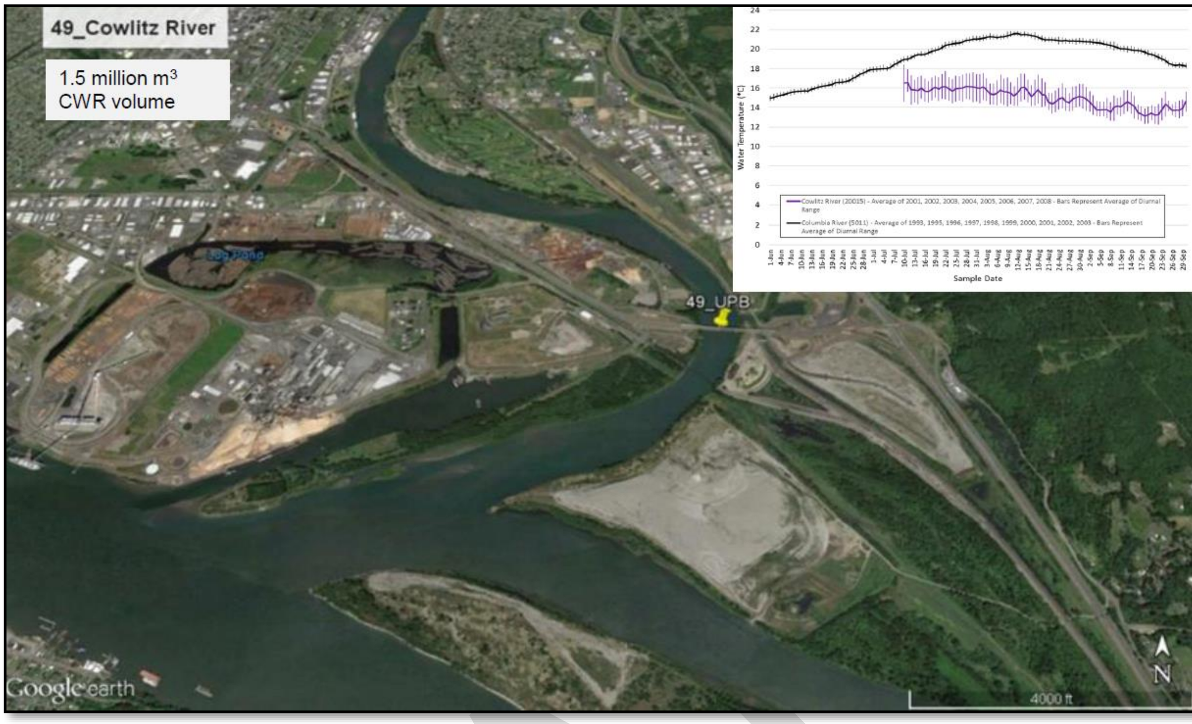


Figure 2-9 Cowlitz River Cold Water Refuge

Figure 2-10 Lewis River Cold Water Refuge

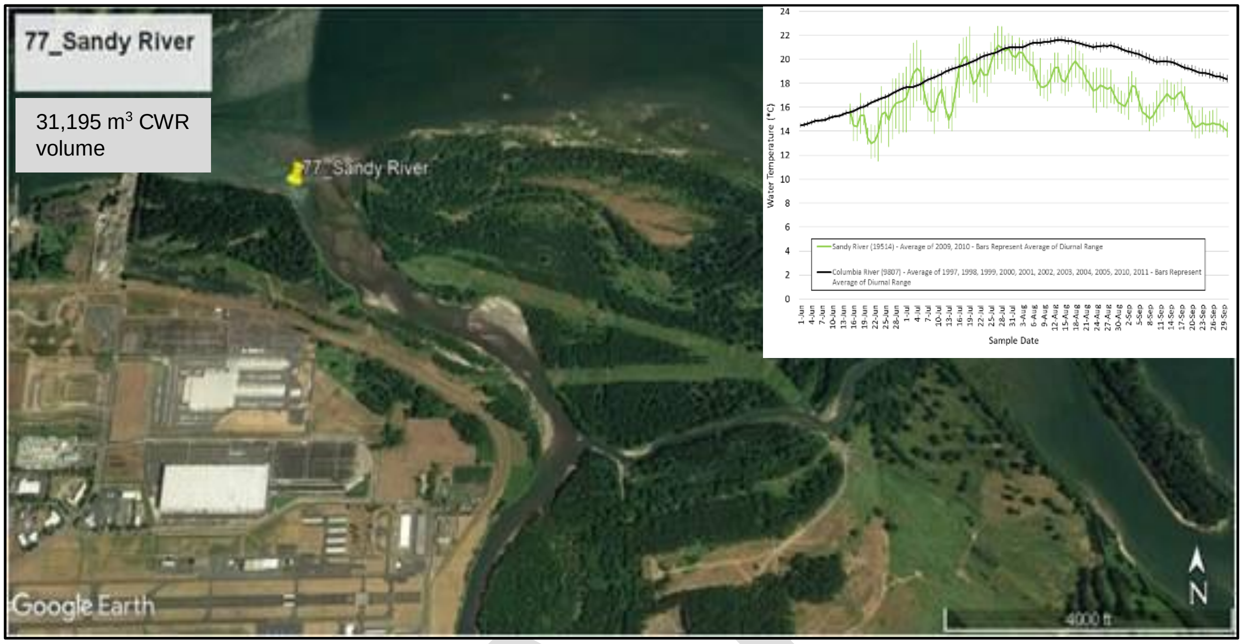


Figure 2-11 Sandy River Cold Water Refuge

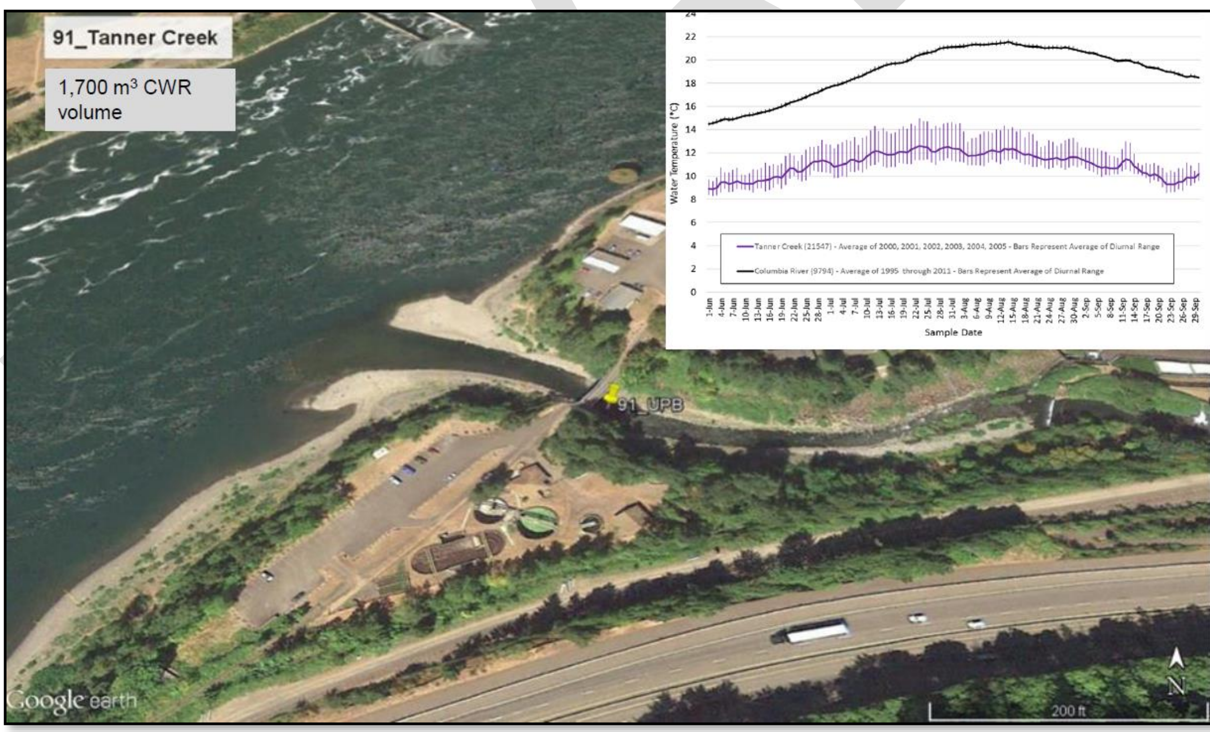


Figure 2-12 Tanner Creek Cold Water Refuge

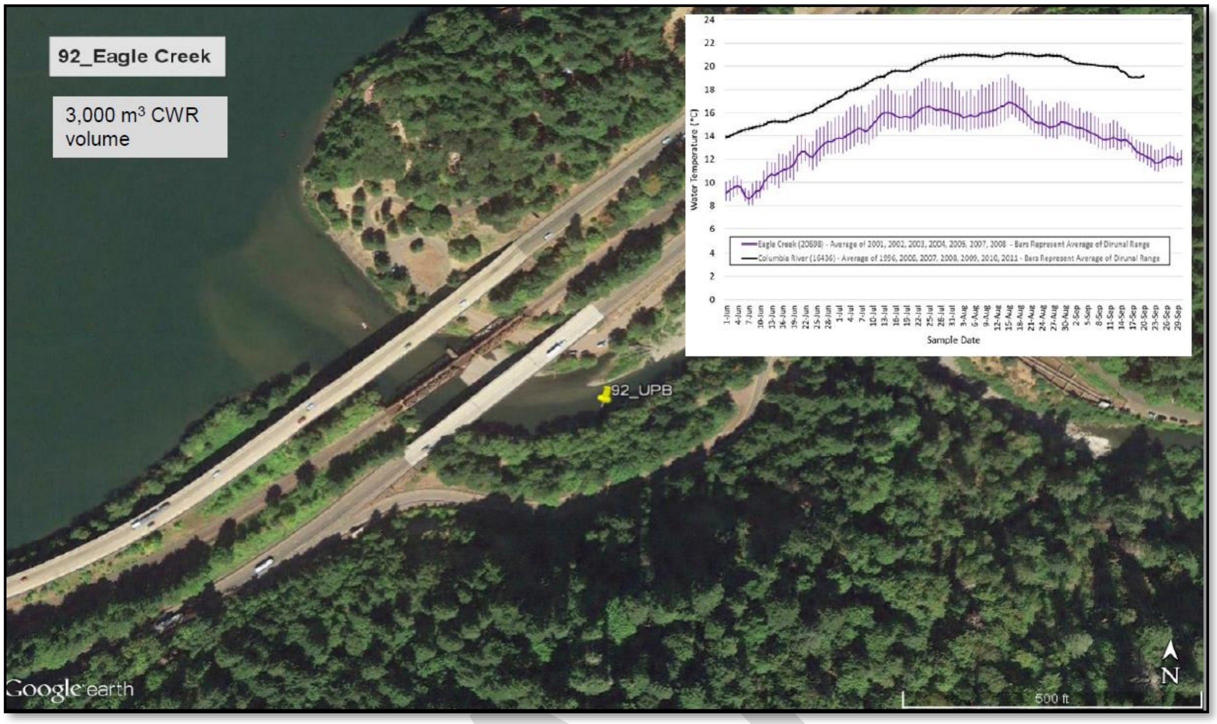


Figure 2-13 Eagle Creek Cold Water Refuge

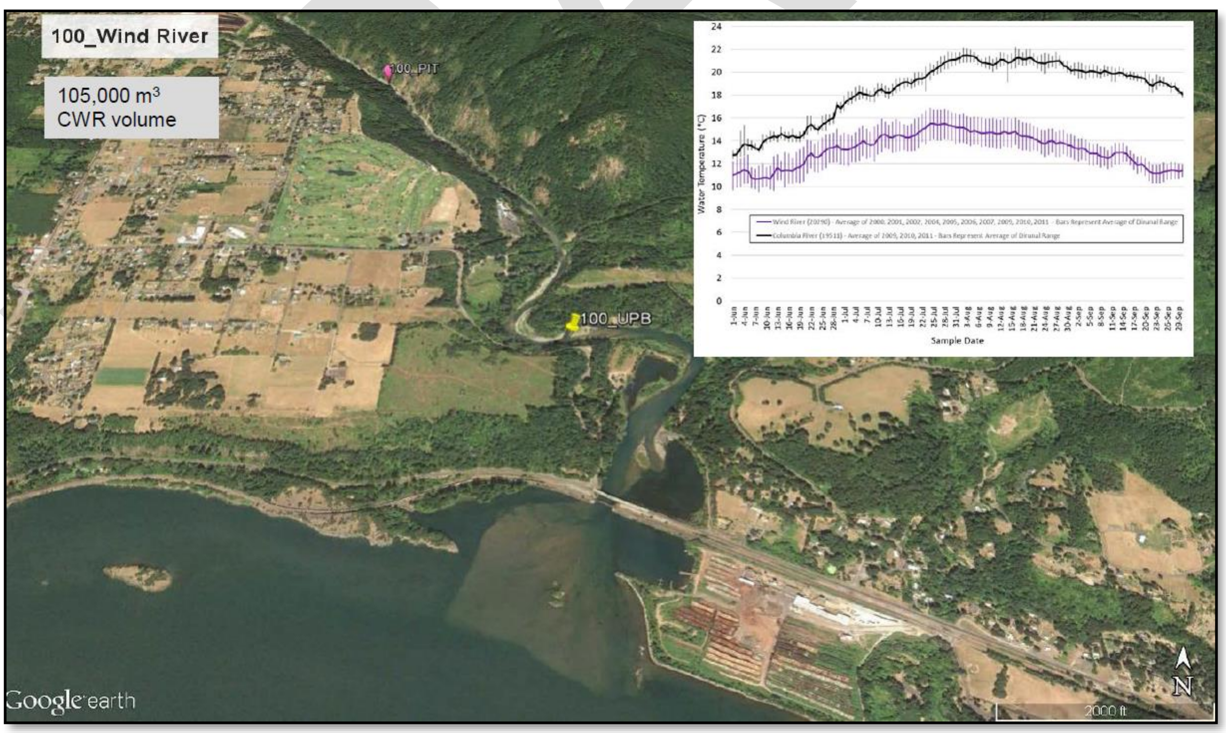


Figure 2-14 Wind River Cold Water Refuge

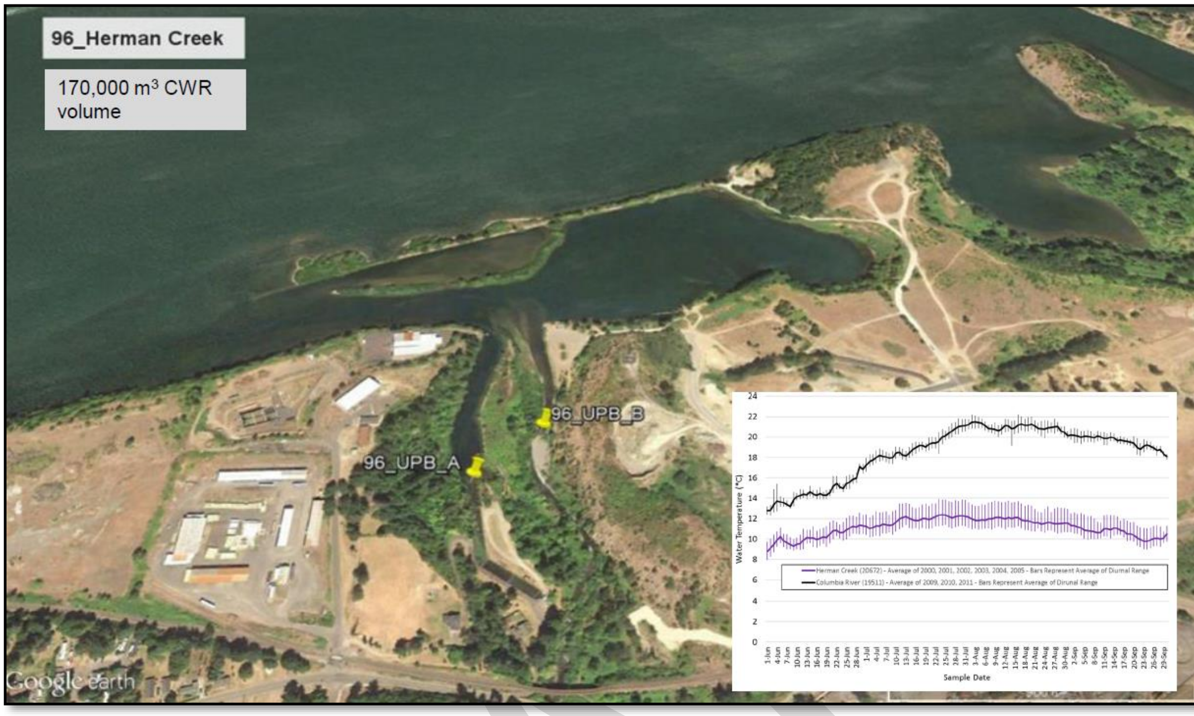


Figure 2-15 Herman Creek and Cove Cold Water Refuge

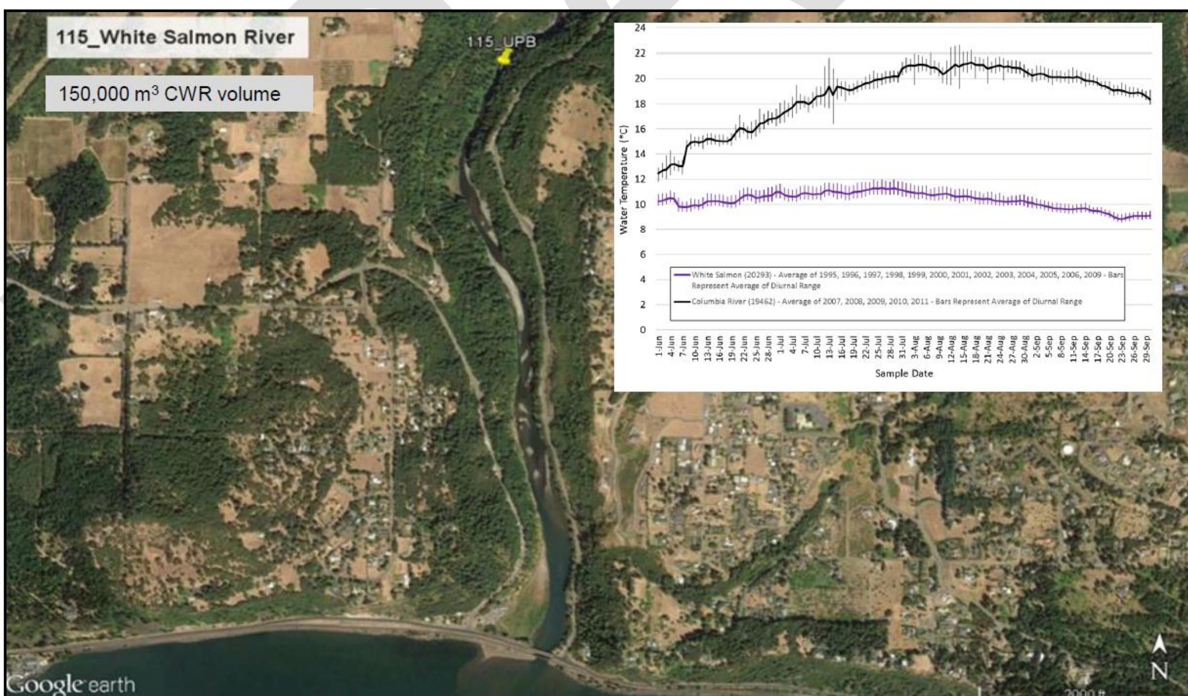


Figure 2-16 White Salmon River Cold Water Refuge

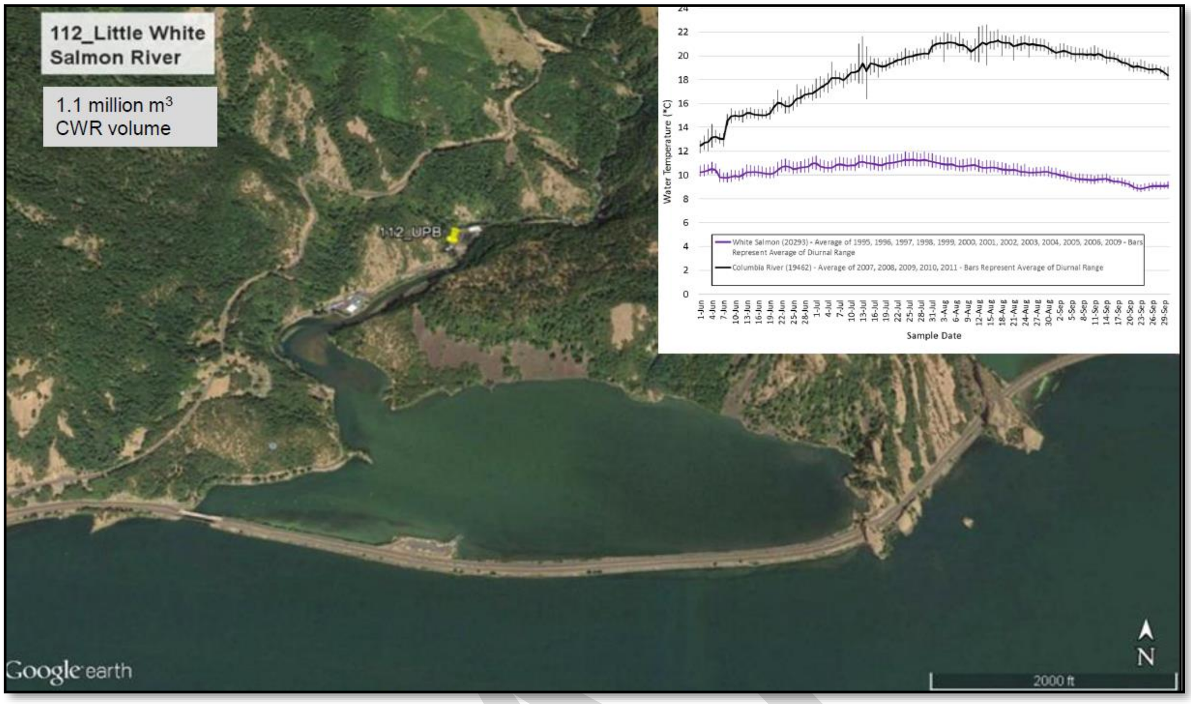


Figure 2-17 Little White Salmon River and Drano Lake Cold Water Refuge

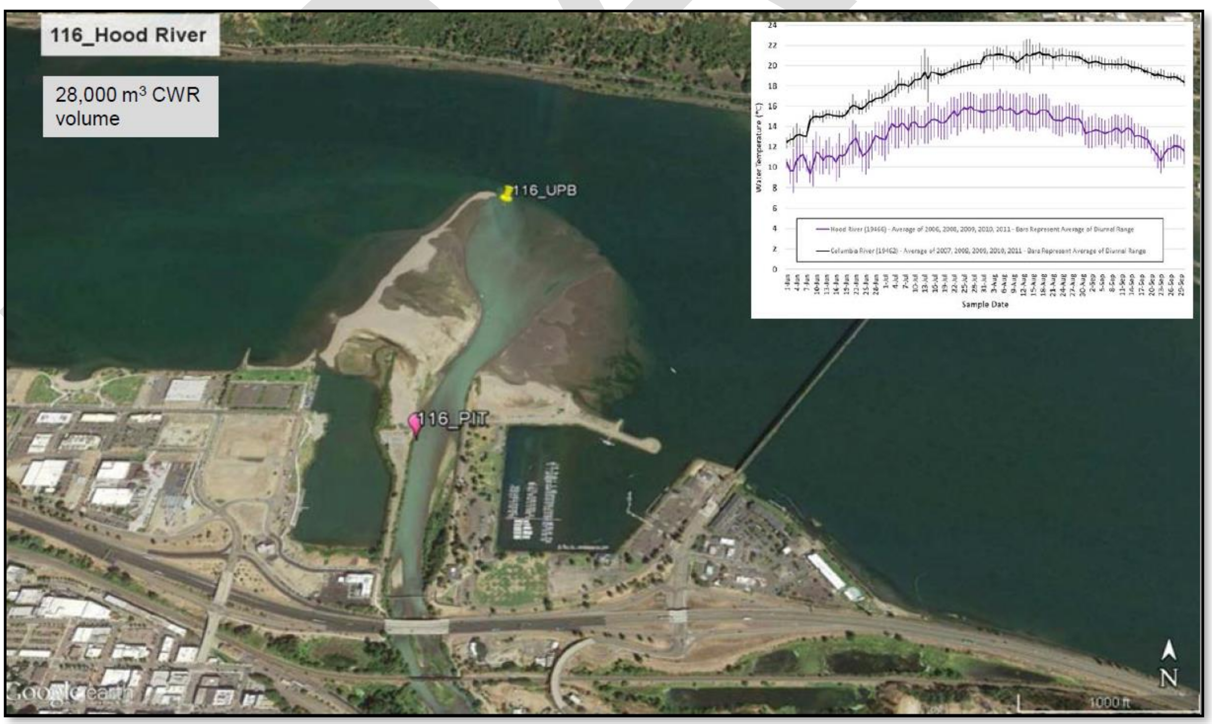


Figure 2-18 Hood River Cold Water Refuge

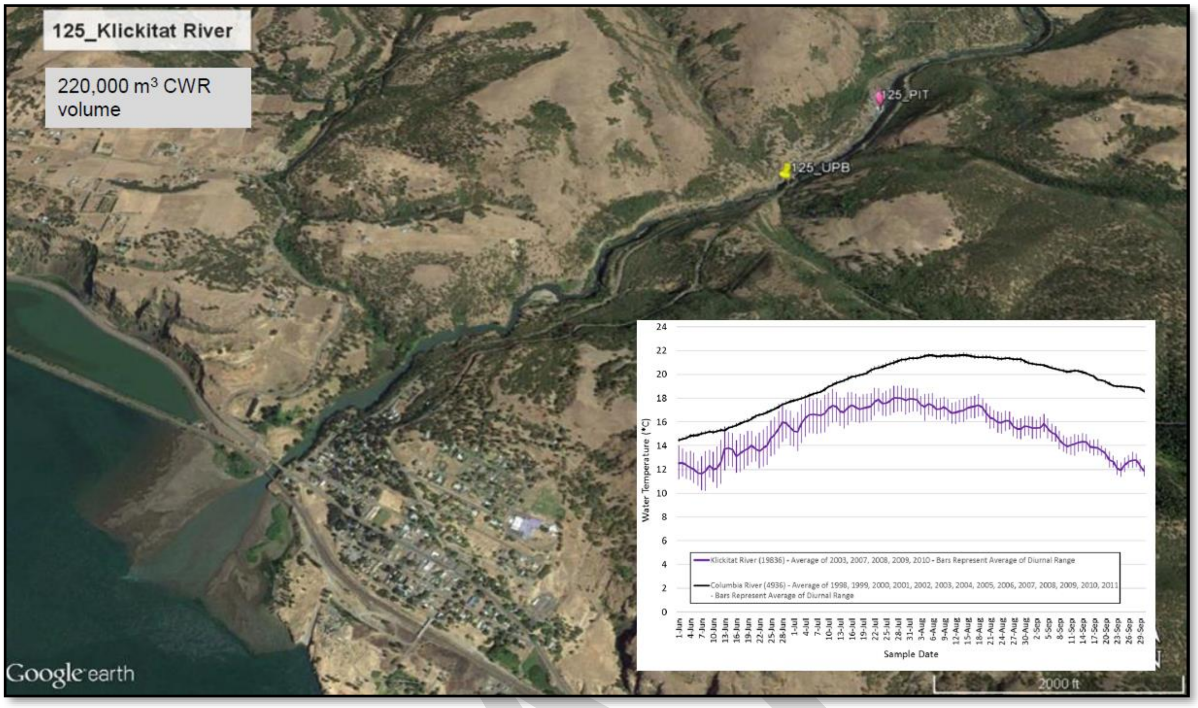


Figure 2-19 Klickitat River Cold Water Refuge

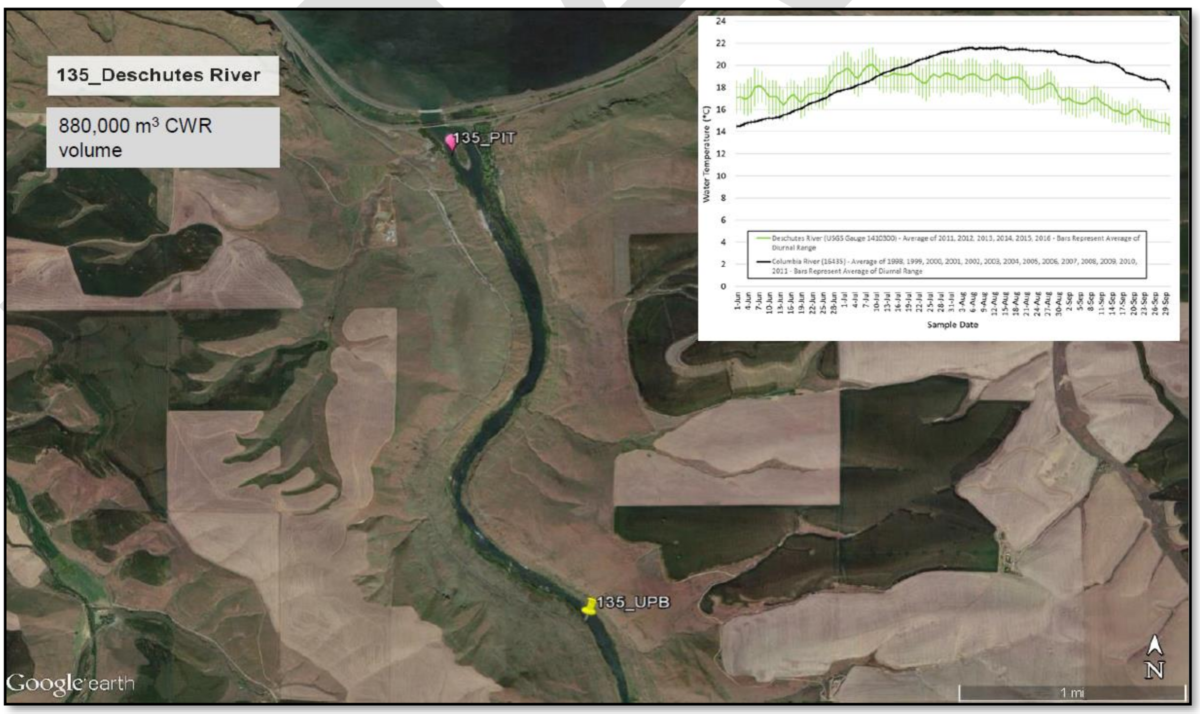


Figure 2-20 Deschutes River Cold Water Refuge

3 SALMON AND STEELHEAD USE OF COLD WATER REFUGES

3.1 SALMON AND STEELHEAD MIGRATION TIMING AND COLUMBIA RIVER TEMPERATURES

The date when fish migrate through the Lower Columbia River and the associated water temperatures is a significant factor in whether or not they will use cold water refuges (CWR). The migration timing of the salmon and steelhead species that migrate up the Columbia River and pass Bonneville Dam each summer is displayed in ***Figure 3-1*** along with the average Columbia River temperature during that time. On average, temperatures in the Lower Columbia River exceed 20°C from mid-July through mid-September and reach peak temperatures of about 22°C in mid-August. The bulk and peak of the summer steelhead run (purple line) migrate past Bonneville Dam during the two-month period when Columbia River temperatures exceed 20°C. The first half of the fall Chinook run (blue line) migrates past Bonneville Dam when temperatures are above 20°C (fall Chinook are defined as Chinook passing Bonneville Dam after August 1st). Accordingly, steelhead and fall Chinook are the species that most often encounter warm Lower Columbia River temperatures and, as discussed later in this chapter, are the species that use CWR the most to escape warm Columbia River temperatures.

Most of the sockeye (green line) and summer Chinook (yellow line) generally pass Bonneville Dam and swim through the Lower Columbia River in June and early July, prior to the onset of warm temperatures (summer Chinook are defined as Chinook passing Bonneville Dam between June 1 and July 31). Accordingly, sockeye and summer Chinook are less likely to use CWR and typically swim continuously through the Lower Columbia River. When the river does warm earlier and coincide with sockeye and summer Chinook fish runs, as it did in 2015, the use of CWR is seen as an ineffective migration strategy for these fish. This appears to be because delayed upstream migration by holding in CWR results in exposure to warmer mainstem temperatures during their continued upstream migration as river temperatures continue to heat up from early to mid-summer.

Due to their extensive use of CWR, this chapter focuses on characterizing summer steelhead and fall Chinook use of CWR in the Lower Columbia River.

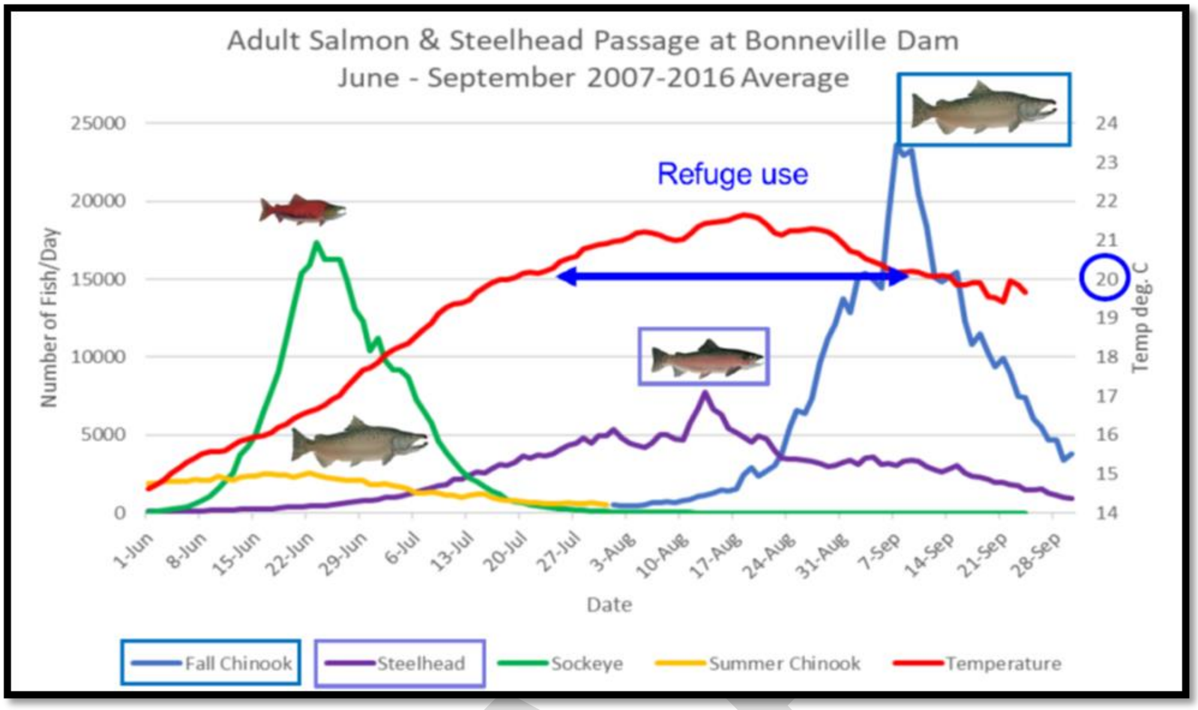


Figure 3-1 Salmon and steelhead Bonneville Dam passage and temperature (DART)

3.2 COLUMBIA RIVER TEMPERATURES THAT TRIGGER COLD WATER REFUGE USE

In the early 2000s, the University of Idaho's Department of Fish and Wildlife Sciences and NOAA Fisheries, under contract with the U.S. Army Corps of Engineers, conducted a series of salmon and steelhead studies using radio-tagged fish to track movement and temperature during migration up the Columbia River. These studies characterized salmon and steelhead use of CWR in the Lower Columbia River. The study results have been summarized in several scientific journals (Goniea et al. 2006, High et al. 2006, Keefer et al. 2009, Keefer et al. 2018) and in the USACE 2013 Report titled "Location and Use of Adult Salmon Thermal Refugia in the Lower Columbia and Snake River" (USACE 2013).

Figure 3-2 and ***Figure 3-3*** show the relationship between Columbia River water temperature and CWR use for steelhead and fall Chinook salmon (USACE 2013). As shown in ***Figure 3-2***, migrating steelhead begin to use CWR when the Columbia River temperature reaches 19°C, and when temperatures are 20°C or higher approximately 60-80% of the steelhead use CWR. As shown in ***Figure 3-3***, fall Chinook initiate use of CWR at slightly warmer temperatures (20-21°C), and about 40% use CWR when temperatures reach 21-22°C.

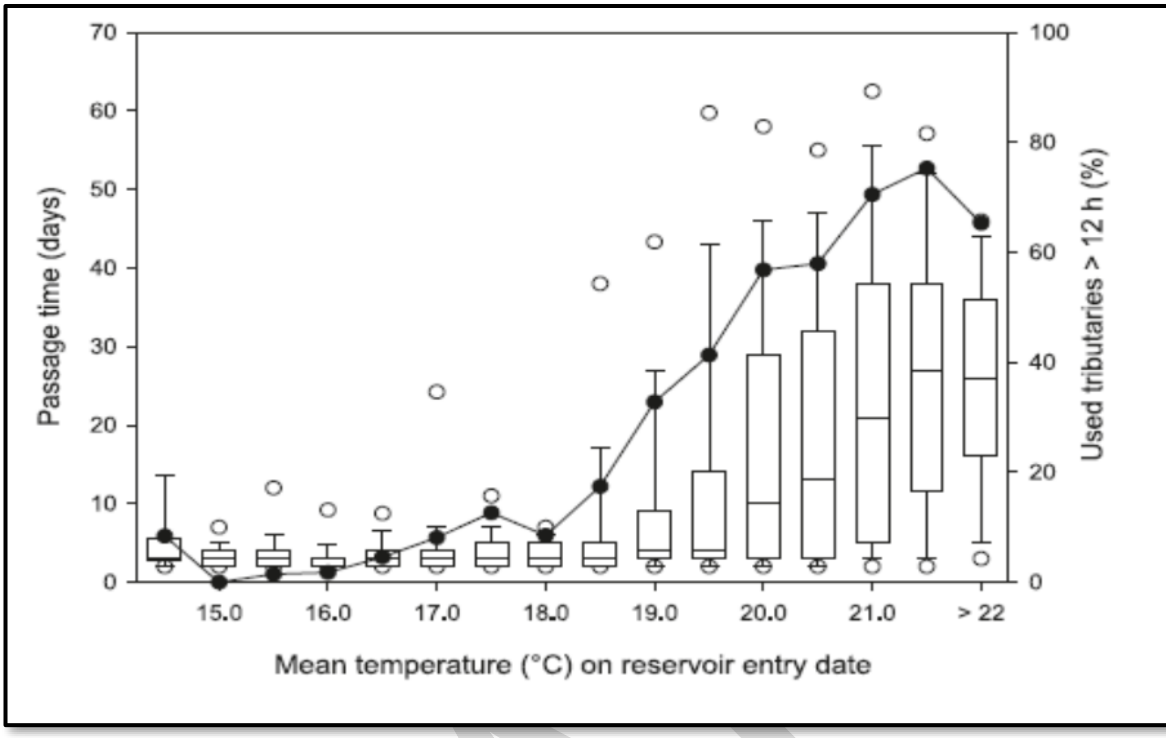


Figure 3-2 Steelhead use of cold water refuge (black dots and 'Used tributaries' axis) (Keefer et. al. 2009)

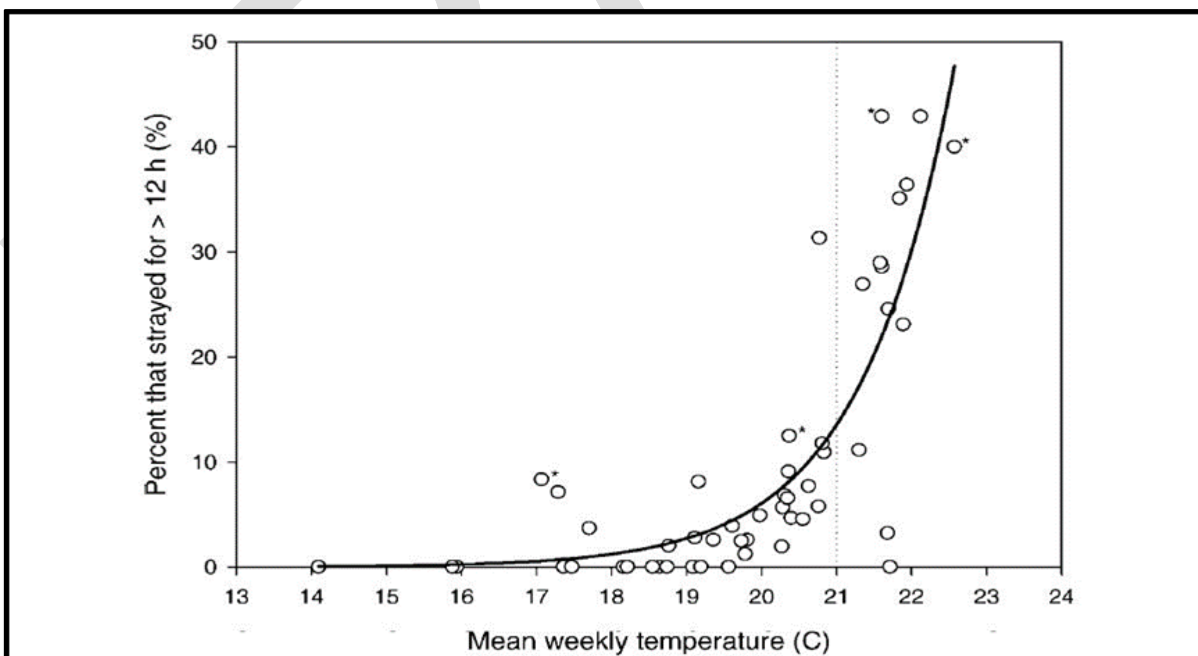


Figure 3-3 Fall Chinook use of cold water refuge (Goniea et. al. 2006)

3.3 EXAMPLES OF SALMON AND STEELHEAD USE OF COLD WATER REFUGES

It is enlightening to look at tracking study results for individual fish with internal temperature sensors to illustrate how fish use CWR. ***Figure 3-4*** shows the temperatures experienced by an individual steelhead between the Bonneville Dam and The Dalles Dam. This steelhead quickly swam from Bonneville Dam to the Little White Salmon River (Drano Lake) and stayed there for approximately two weeks, then quickly swam up the Columbia River to the White Salmon River, where it stayed for about five days before proceeding to pass The Dalles Dam. This figure provides an example of how steelhead use CWR (for approximately three weeks in this case) to minimize their exposure to warm Columbia River temperatures as they wait for the river (gray line) to cool off before they continue their upward migration to spawn.

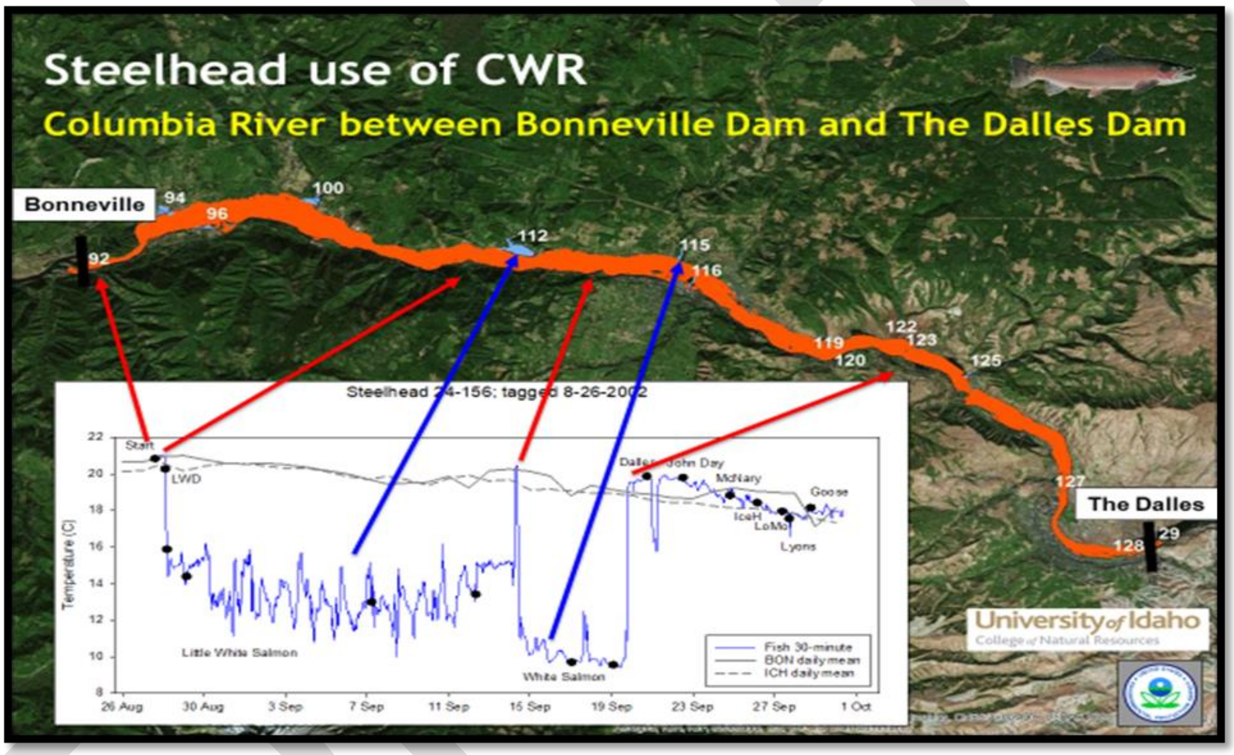


Figure 3-4 Temperature profile of a steelhead using cold water refuges (Keefer & Caudill 2017)

Figure 3-5 shows another steelhead exhibiting a similar pattern of CWR use. This steelhead used Herman Creek/Cove, the Little White Salmon River (Drano Lake), an unknown CWR (potentially the mouth of the Klickitat River) between Bonneville Dam and The Dalles Dam. It then took refuge in the Deschutes River CWR for a few days prior to proceeding up the Columbia and Snake Rivers. ***Figure 3-5*** shows how a steelhead can minimize its exposure to elevated temperatures during its upstream migration in August and continue migrating upstream in September when temperatures begin to cool.

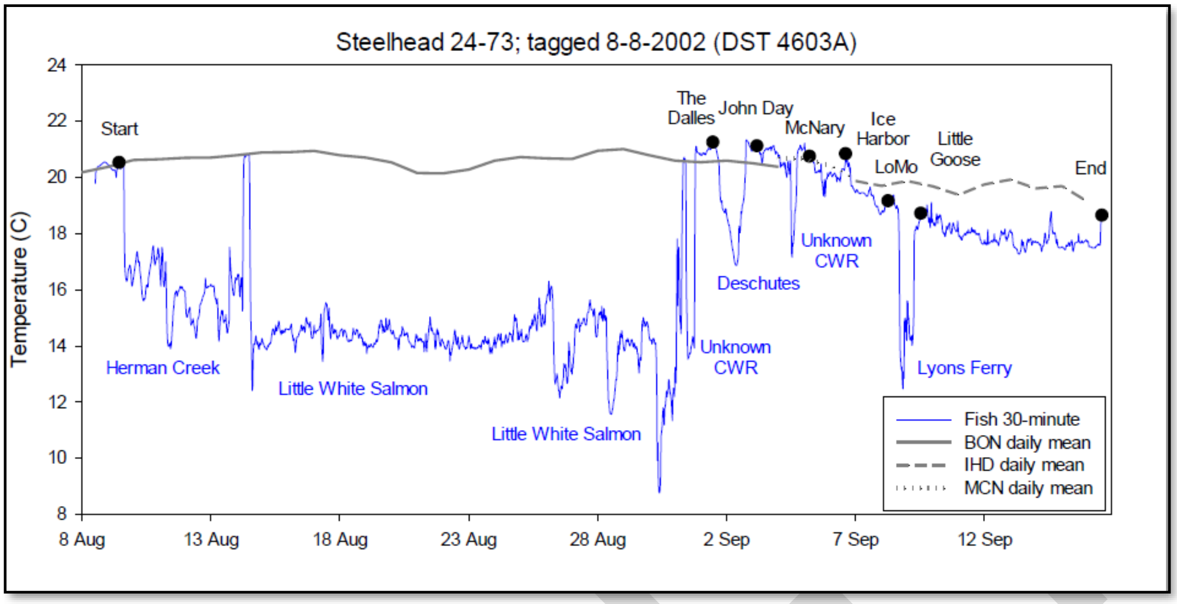


Figure 3-5 Temperature profile of a steelhead using cold water refuges (Keefer & Caudill 2017)

Figure 3-6 shows the temperature profile of a fall Chinook salmon. Fall Chinook salmon also utilize CWR as part of their migration strategy, but not for as long as steelhead. Scientists hypothesize that this is in part because fall Chinook spawn in the fall in upstream rivers and are genetically driven to move to their spawning grounds in time to spawn (Goniea et al. 2006). Conversely, steelhead spawn in the late winter and spring, so they have more time and flexibility in their migration timing to reach their upstream spawning grounds (Keefer et al. 2009 and Keefer et al. 2018). The fall Chinook in ***Figure 3-3*** used the Little White Salmon (Drano Lake), the White Salmon, and an unknown CWR area (potentially the Klickitat River) for a few days combined between Bonneville Dam and The Dalles Dam, then found an unknown CWR area near McNary Dam.

Figure 3-7 shows the temperature profile for a summer Chinook salmon. As reflected in ***Figure 3-1***, summer Chinook salmon migrate past Bonneville Dam in June and July, typically prior to the on-set of warmer Columbia River temperatures. However, those summer Chinook that pass Bonneville Dam in late July, like the one shown in ***Figure 3-7***, can be exposed to warm Columbia River temperatures greater than 20°C. This summer Chinook used the Deschutes River CWR for a brief time prior to proceeding upriver. Use of CWR for an extended period is not likely to be a beneficially adapted trait for summer Chinook salmon, because they migrate when Columbia River temperatures are rising. Thus, if a summer Chinook held in a CWR for a week, it would end up experiencing higher Columbia River temperatures during the rest of its migration in the Lower Columbia River. It appears to be more advantageous for summer Chinook to quickly migrate through the Lower Columbia River to avoid the warmest temperatures that generally occur in late July and August. However, brief respites in CWR could provide some physiological benefit to summer Chinook.

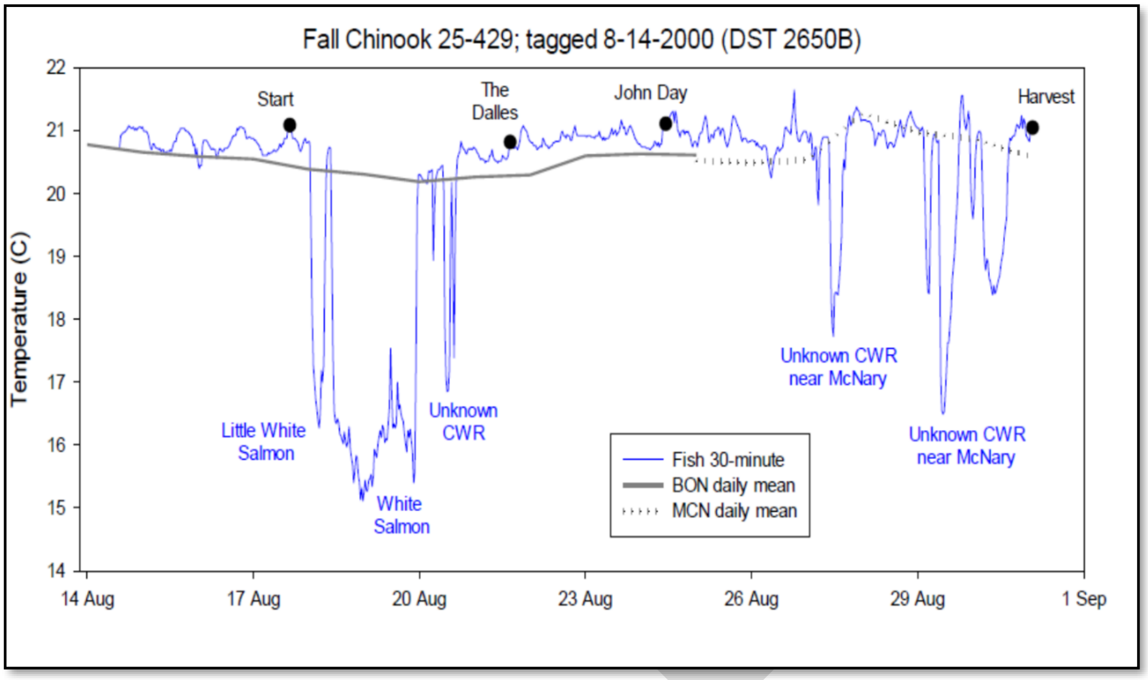


Figure 3-6 Temperature profile of a fall Chinook salmon using cold water refuges (Keefer & Caudill 2017)

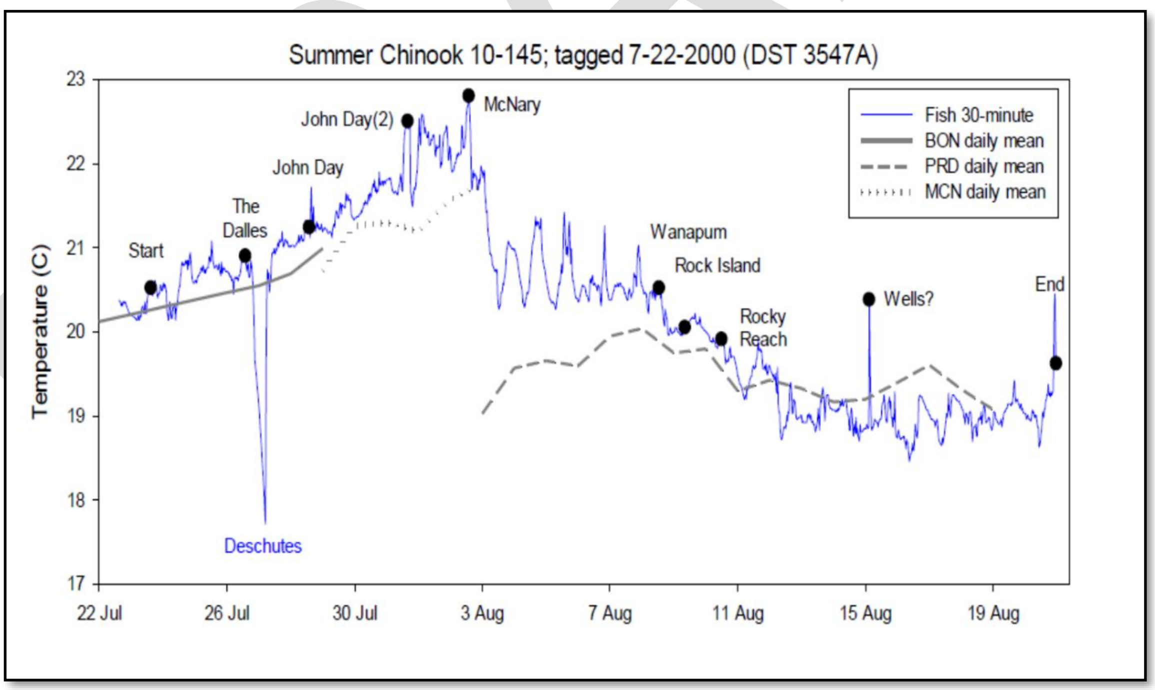


Figure 3-7 Temperature profile of a summer Chinook salmon using cold water refuges (Keefer & Caudill 2017)

3.4 STEELHEAD USE OF COLD WATER REFUGES

The research conducted by the University of Idaho and NOAA Fisheries demonstrates that salmon and steelhead move in to CWR in the Lower Columbia River to avoid warm Columbia River temperatures. However, there are no research studies estimating the number of salmon and steelhead that are in the respective CWR areas.

EPA developed a method to estimate the number of steelhead in the CWR between Bonneville Dam and The Dalles Dam by using daily passage counts of steelhead at these two dams from DART. ***Figure 3-8*** shows the average steelhead passage counts at each of the two dams and the average Columbia River temperature at Bonneville Dam from 2007 to 2016. This figure shows that as temperatures reach 20°C, many steelhead that pass Bonneville Dam in late July and August (blue line) wait until September to pass The Dalles Dam (green line). Since more steelhead are entering the Bonneville reach than leaving the reach during this time, it results in an accumulation of steelhead within the Bonneville reach, which can be estimated. EPA estimated the number of accumulated steelhead by summing the daily count of steelhead passing Bonneville Dam minus the daily count passing The Dalles Dam and subtracting the percentage of steelhead not expected to pass The Dalles Dam due to fishing harvest, straying, and those returning to spawn in Bonneville reach tributaries. EPA estimated the percentage of accumulated steelhead that is in the reservoir versus in CWR using scientific literature on the relationship of temperature and the percentage of steelhead that enter CWR and on the migration travel time between the two dams (Appendix 12.13).

Figure 3-9 shows the results of EPA's estimates of the number of steelhead in CWR within the Bonneville reach in an average year (2007-2016). Up to approximately 80,000 steelhead accumulate in the Bonneville reach in August. Of these, approximately 68,000 (85%) are estimated to be inside CWR. The peak occurs in the latter half of August since steelhead continue to accumulate within the reach until about the first of September. At this time, temperatures cool to the point that more steelhead are exiting the reach by passing The Dalles Dam than entering the reach by passing the Bonneville Dam as shown in ***Figure 3-8*** (Appendix 12.13).

To verify the EPA approach to estimating the number of steelhead in Bonneville reach CWR, empirical data from the University of Idaho was evaluated (M. Keefer, personal communication, August 31, 2017). ***Figure 3-10*** shows the daily location of 219 recorded steelhead as they migrate through the Bonneville reach. As shown, on a given day when Columbia River temperatures typically exceed 20°C, the vast majority of steelhead (80-90%) are in CWR and only a portion are in the Columbia River. Further, the peak accumulation of steelhead in CWR occurred in the latter half of August/early September. Thus, the EPA estimation approach matches the pattern and percentage of radio-tagged steelhead in Bonneville reach CWR very closely.

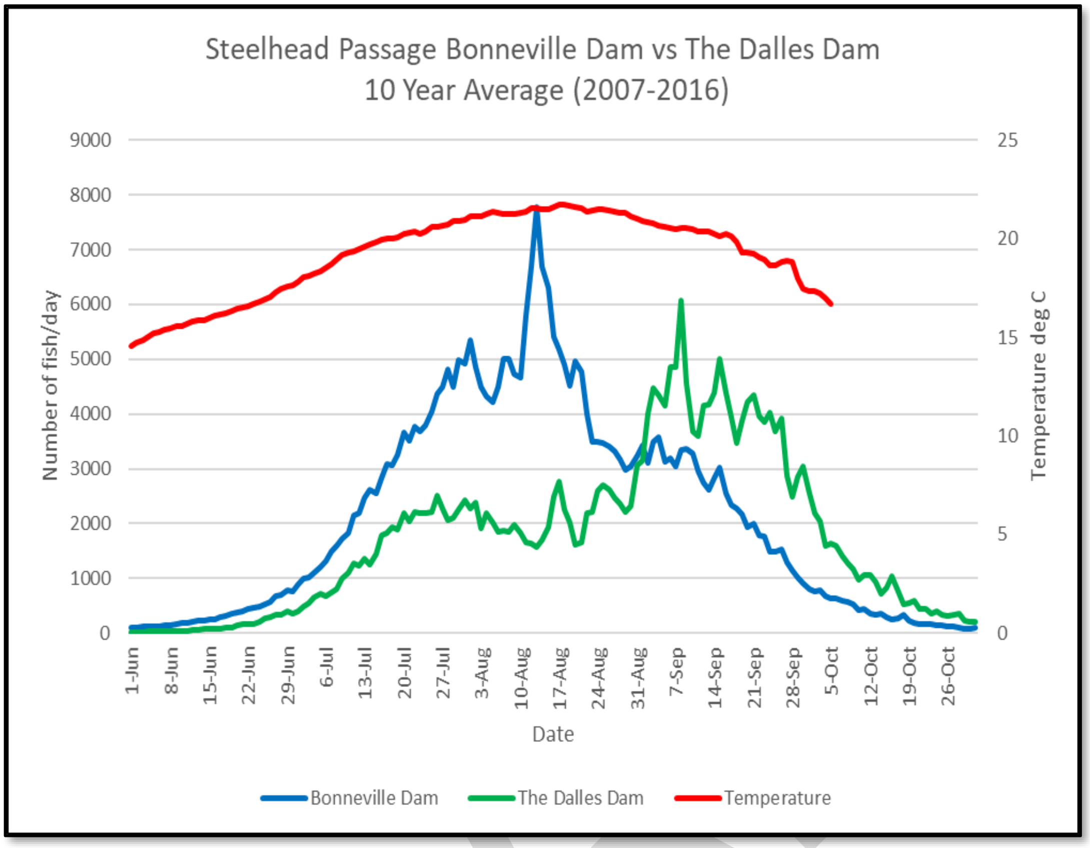


Figure 3-8 Steelhead passage at Bonneville Dam and The Dalles Dam (Appendix 12.13)

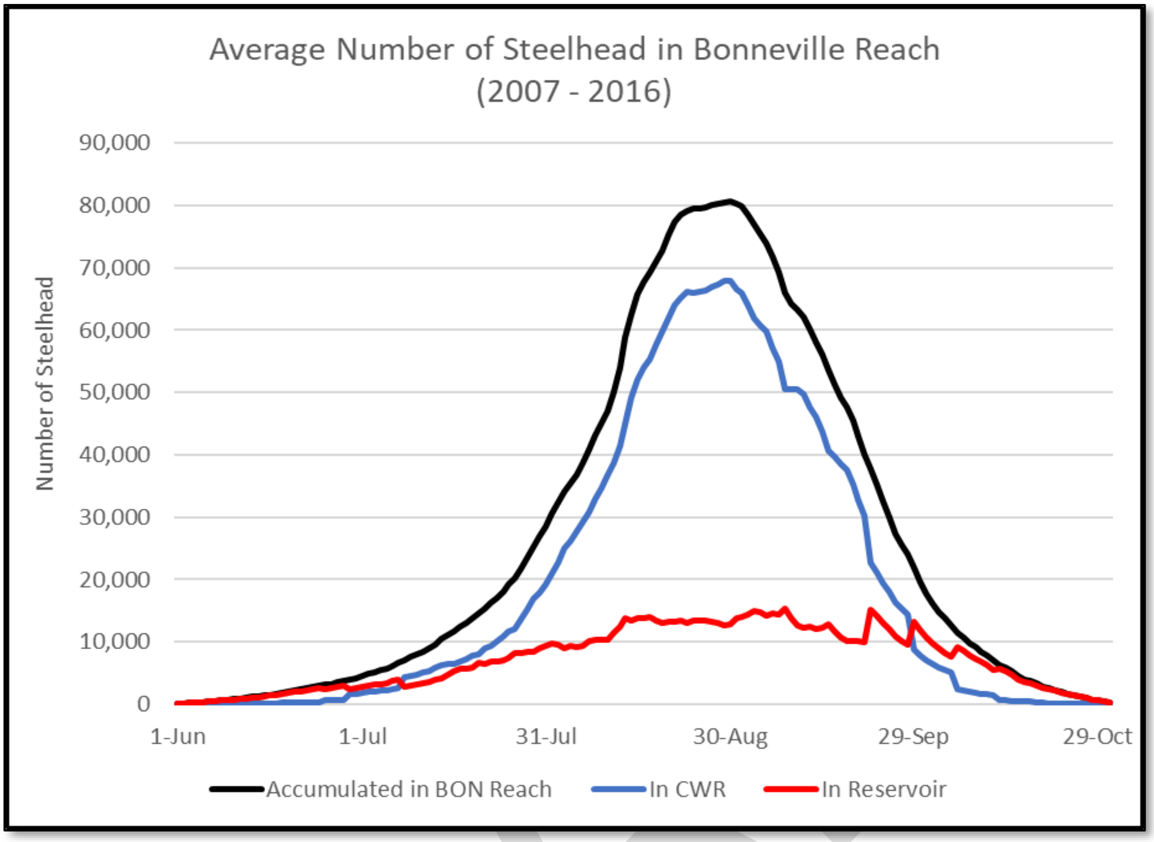


Figure 3-9 Estimated number of steelhead in Bonneville reach cold water refuges (Appendix 12.13)

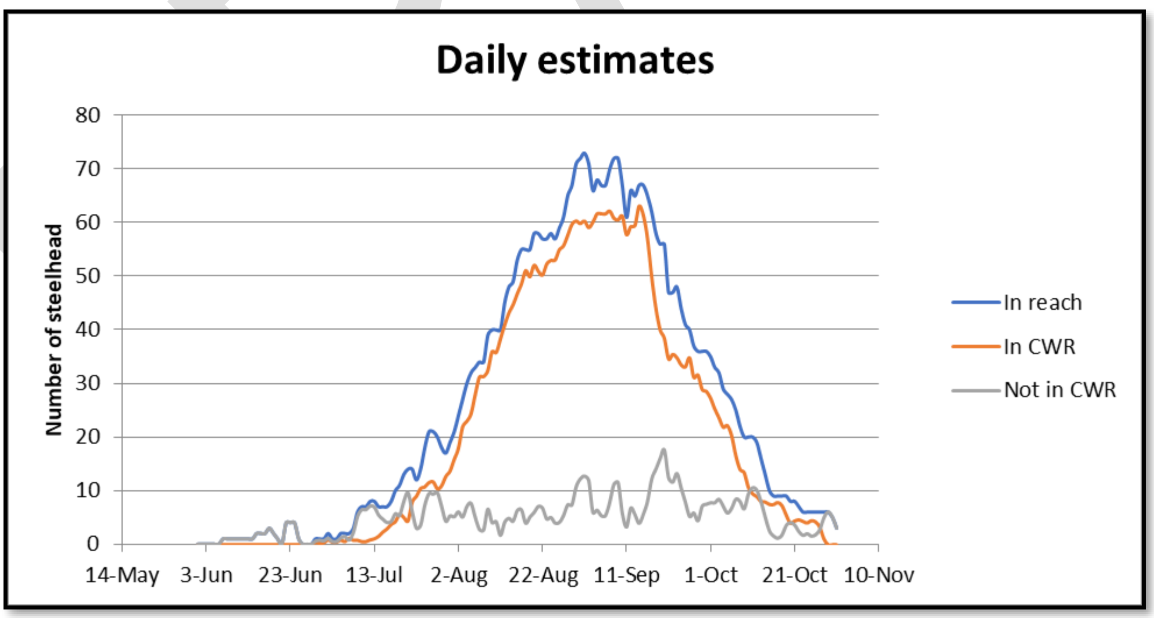


Figure 3-10 Proportion of 219 radio-tagged steelhead in Bonneville cold water refuges (M. Keefer, personal communication, August 31, 2017)

EPA applied a simplified approach to estimate the number of steelhead in Bonneville reach CWR for individual years from 1999 through 2016, which is shown in ***Table 3-1*** (Appendix 12.13). The simplified approach estimates the peak number of steelhead that accumulate in the Bonneville reach by taking the number of steelhead that would pass The Dalles Dam for the July 15 - August 30 period if steelhead were not using CWR (expected to pass) and subtracting the number of steelhead that actually pass The Dalles Dam during this period. Of the number of accumulated steelhead in the Bonneville reach during the peak accumulation period (late August), 85% were assumed to be in CWR (Appendix 12.13).

As shown in ***Table 3-1***, the number of steelhead in CWR varies year to year and is primarily a function of the size of the steelhead run (number passing Bonneville Dam) and the Columbia River temperature. During a year with a large steelhead run and warm Columbia River temperatures (2009), 155,000 steelhead are estimated to be in Bonneville reach CWR. During a year with a small steelhead run and cool Columbia River temperatures (2012), only 23,000 steelhead are estimated to be in CWR.

Table 3-1 Estimated number of steelhead in cold water refuges each year (1999-2016) (Appendix 12.13)

Year	Ave Temp July 15 -Aug 31	Passed BON July 15 -Aug 31	Passed Dalles July 15 -Aug 31	Measured % That Passed Dalles June 1-Oct 31	Expected to Pass Dalles July 15 -Aug 31	In BON Reach Peak	In CWR (85%) Peak
2016	21.4	83,919	24,212	80%	66,868	42,656	36,258
2015	21.8	165,138	69,059	84%	137,893	68,834	58,509
2014	21.5	175,686	70,488	80%	140,923	70,435	59,869
2013	21.5	166,926	68,949	83%	138,059	69,110	58,743
2012	20.1	142,032	95,612	86%	122,797	27,185	23,107
2011	19.5	252,331	176,573	82%	207,452	30,879	26,248
2010	21.0	231,804	121,974	82%	189,445	67,471	57,350
2009	21.6	451,509	205,163	86%	388,094	182,931	155,492
2008	20.0	225,506	117,044	79%	177,048	60,004	51,004
2007	21.1	229,124	83,820	76%	173,420	89,600	76,160
2006	21.1	187,415	53,379	72%	134,561	81,182	69,005
2005	21.4	175,028	55,866	77%	135,090	79,224	67,340
2004	22.0	155,516	42,744	78%	120,905	78,161	66,437
2003	21.7	209,328	58,083	77%	160,904	102,821	87,398
2002	20.4	257,857	131,121	82%	210,238	79,117	67,250
2001	20.7	397,879	169,554	80%	319,544	149,990	127,491
2000	20.6	164,593	75,954	75%	124,114	48,160	40,936
1999	20.0	136,136	76,782	77%	104,458	27,676	23,524
Average	20.9	219,048	98,363		175,585	77,222	65,639

Table 3-2 includes the estimated number of steelhead in each of the eight CWR in the Bonneville reach between Bonneville Dam and The Dalles Dam using the CWR volumes from ***Table 2-2*** and ***Table 2-3*** as an approximate indicator of the distribution of steelhead in the eight CWR. Over half of the steelhead (61%) are expected to be in the Little White Salmon (Drano

Lake) CWR with approximately 40,000 steelhead during the peak period for an average year, with peaks ranging from 14,000 to 95,000 steelhead in low and high years. Other Bonneville reach CWR tributaries with extensive steelhead CWR include Herman Creek, White Salmon River, Wind River, and the Klickitat River.

Table 3-2 Estimated number of steelhead in each Bonneville reach cold water refuge (Appendix 12.13)

Tributary Name	Tributary Temp	Plume CWR Volume (>2°C Δ)	Stream CWR Volume (>2°C Δ)	Total CWR Volume (>2°C Δ)	% of CWR in BON Reach	# Steelhead in Each CWR (1999-2016 Ave)	# Steelhead in Each CWR High Year (2009)	# Steelhead in Each CWR Low Year (2012)
	°C	m3	m3	m3				
Eagle Creek	15.1	2,100	888	2,988	0.2%	110	260	39
Rock Creek	17.4	530	1,178	1,708	0.1%	63	149	22
Herman Creek	12.0	168,000	1,698	169,698	9.5%	6,243	14,788	2,198
Wind River	14.5	60,800	44,420	105,220	5.9%	3,871	9,169	1,363
Little White Salmon River	13.3	1,097,000	4,126	1,101,126	61.7%	40,507	95,957	14,260
White Salmon River	15.7	72,000	81,529	153,529	8.6%	5,648	13,379	1,988
Hood River	15.5	28,000	0	28,000	1.6%	1,030	2,440	363
Klickitat River	16.4	73,000	149,029	222,029	12.4%	8,168	19,349	2,875
Total		1,501,430	282,868	1,784,298	100%	65,639	155,492	23,107

To verify the EPA approach to estimate the number of steelhead in each CWR, empirical data from the University of Idaho was evaluated (M. Keefer, personal communication, September 11, 2017). ***Table 3-3*** shows the distribution of 59 radio-tagged steelhead in the Bonneville reach CWR on August 31, which represents the time of peak CWR use. The distribution in ***Table 3-3*** is generally consistent with predicting the number of steelhead in each CWR based on volume shown in ***Table 3-2***, with a large percentage (68%) of the steelhead in the Little White Salmon River (Drano Lake) and a significant percentage (greater than 7%) in Herman Creek, White Salmon River, and the Klickitat River CWR.

Table 3-3 Distribution of radio-tagged steelhead in the Bonneville reach cold water refuges on August 31 (Combined 2000/2001 Data Set) (M. Keefer, personal communication, September 11, 2017)

CWR Location	31-Aug	%	Predicted based on CWR Volume
Herman Creek	6	10%	10%
Wind River	1	2%	6%
Little White Salmon/Drano Lake	40	68%	62%
White Salmon	4	7%	9%
Klickitat River	4	7%	12%
Unknown CWR	4	7%	
Total	59 Steelhead		

Table 3-4 shows the estimated density of steelhead in Bonneville reach CWR under different run size scenarios (average, high, low) and for the two different volume metrics of CWR (volume that is 2°C cooler than the Columbia River and volume that is 18°C or cooler). The density is estimated by dividing the estimated number of steelhead by the CWR volume. The density associated with 18°C or cooler volume may be a better indicator of density, because steelhead residing for an extended period are likely to seek temperatures below 18°C. The maximum estimated density of steelhead is 0.16 steelhead per cubic meter, which is 407 steelhead in an Olympic-sized swimming pool (Appendix 12.13).

Table 3-4 Estimated steelhead density in cold water refuges (Appendix 12.13)

	CWR Volume (> 2°C Δ)			CWR Volume (< 18°C)		
	Average	High	Low	Average	High	Low
	1999-2016	2009	2012	1999 -2016	2009	2012
# fish/m3	0.0368	0.0871	0.0130	0.0688	0.1630	0.0242
# fish/2500 m3	92	218	32	172	407	61

3.5 FALL CHINOOK USE OF COLD WATER REFUGES

EPA used the methods described above for steelhead to estimate the number of fall Chinook using CWR in the Bonneville reach. As shown in ***Figure 3-11***, the estimated number of fall Chinook in CWR (green line) is estimated to be approximately 5,000 during the last week of August and the first two weeks of September for an average year (2008-2017) (Appendix 12.13). This figure shows that, unlike steelhead, the majority of fall Chinook in the Bonneville reach are estimated to be migrating in the reservoir. After mid-September, the number of fall Chinook passing Bonneville Dam begins to decrease and the accumulated number of fall Chinook in the reach begins to decrease as temperatures fall to 20°C and below.

In warmer years such as 2013, when temperatures remain above 21°C into early September during the peak of the fall Chinook run, EPA estimates a higher proportion of fall Chinook will use CWR within the Bonneville reach to avoid mainstem temperatures. As shown in ***Figure 3-12***, 20,000 to 40,000 fall Chinook are estimated to have been in Bonneville reservoir CWR in 2013 in the latter part of August through mid-September (green line). This is four to eight times the estimated number of 5,000 fall Chinook in CWR in an average year (see ***Figure 3-11***). Late August and early September temperatures were consistently around 22°C in 2013, which are temperatures at which a significant number of fall Chinook seek CWR. 2013 also represents a relatively high run year with 953,222 adult fall Chinook passing Bonneville Dam, which is about twice the 10-year (2007-2016) annual average of 504,148 (FPC 2014 & 2016 Annual Report).

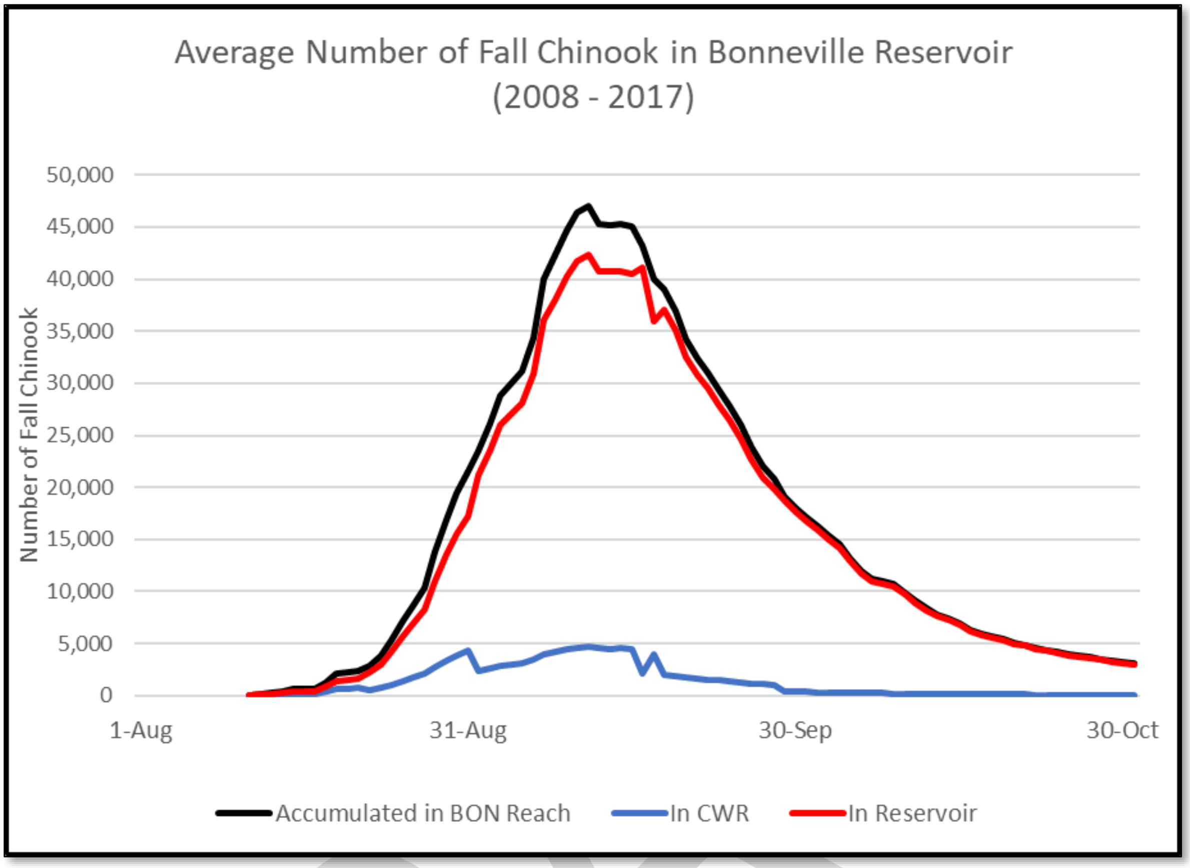


Figure 3-11 Accumulation of fall Chinook in the Bonneville reach and the number of fall Chinook in cold water refuges (2008-2017 average) (Appendix 12.13)

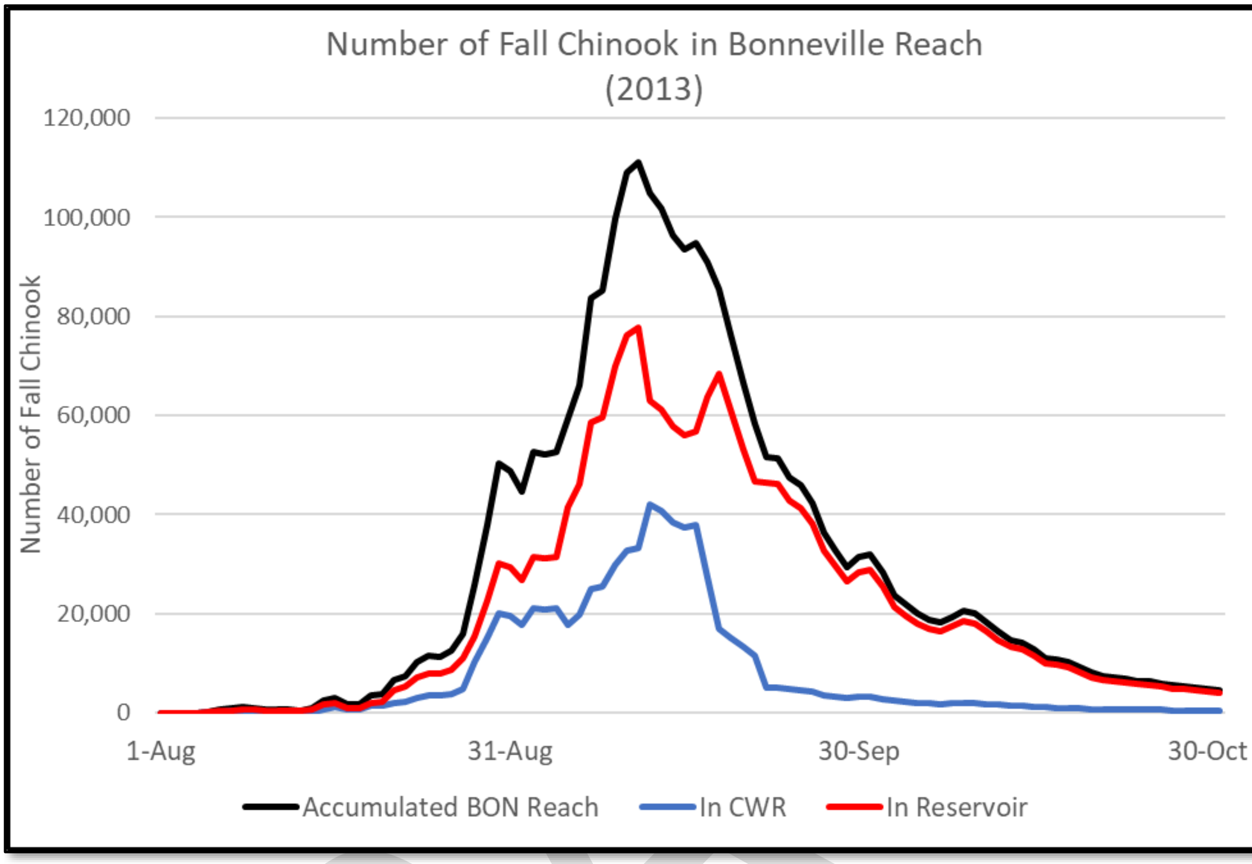


Figure 3-12 Accumulation of fall Chinook in the Bonneville reach and the number of fall Chinook in cold water refuges (2013) (Appendix 12.13)

3.6 SUMMARY OF THE NUMBER OF STEELHEAD AND FALL CHINOOK IN COLD WATER REFUGES

Peak use of Bonneville reservoir CWR by steelhead occurs mid-August through early September and peak use by fall Chinook occurs in late August through mid-September. During an average year (river temperatures and run size), approximately 65,000 steelhead and 5,000 fall Chinook are in Bonneville reservoir CWR. During years with warm August-September Columbia River temperatures and high run size, as many as 155,000 steelhead and 40,000 fall Chinook are predicted to be in Bonneville reservoir CWR during the period of peak refuge use, although these peak numbers for steelhead and fall Chinook may not occur in the same years.

3.7 HISTORIC STEELHEAD USE OF COLD WATER REFUGES

Because The Dalles Dam was built in 1957, the comparison of steelhead passage at the Bonneville Dam versus The Dalles Dam is available since 1957. As shown in ***Figure 3-8*** above, passage data from the last decade shows there is a significant delay in steelhead passage over The Dalles Dam and accumulation of steelhead in the Bonneville reach during the period of summer maximum temperatures. Conversely, as shown in ***Figure 3-13***, there is not a significant delay over The Dalles Dam in the decade after The Dalles Dam was built (1957-

1966). Limited temperature data collected in the 1950s depicted in ***Figure 3-14*** shows summer peak temperatures were lower compared to current day temperatures. Current daily average temperatures exceed 20°C for about two months and exceed 21°C for one month, but during the 1950s daily average temperatures typically only exceeded 20°C for a short period (a week) and did not exceed 21°C. And, as described earlier, >20°C temperatures are associated with a high level of CWR use by steelhead. These data suggest steelhead use of CWR in the Bonneville reach was historically less than what we observe currently, and that steelhead are using CWR more today in response to increased summer temperatures of the Lower Columbia River.

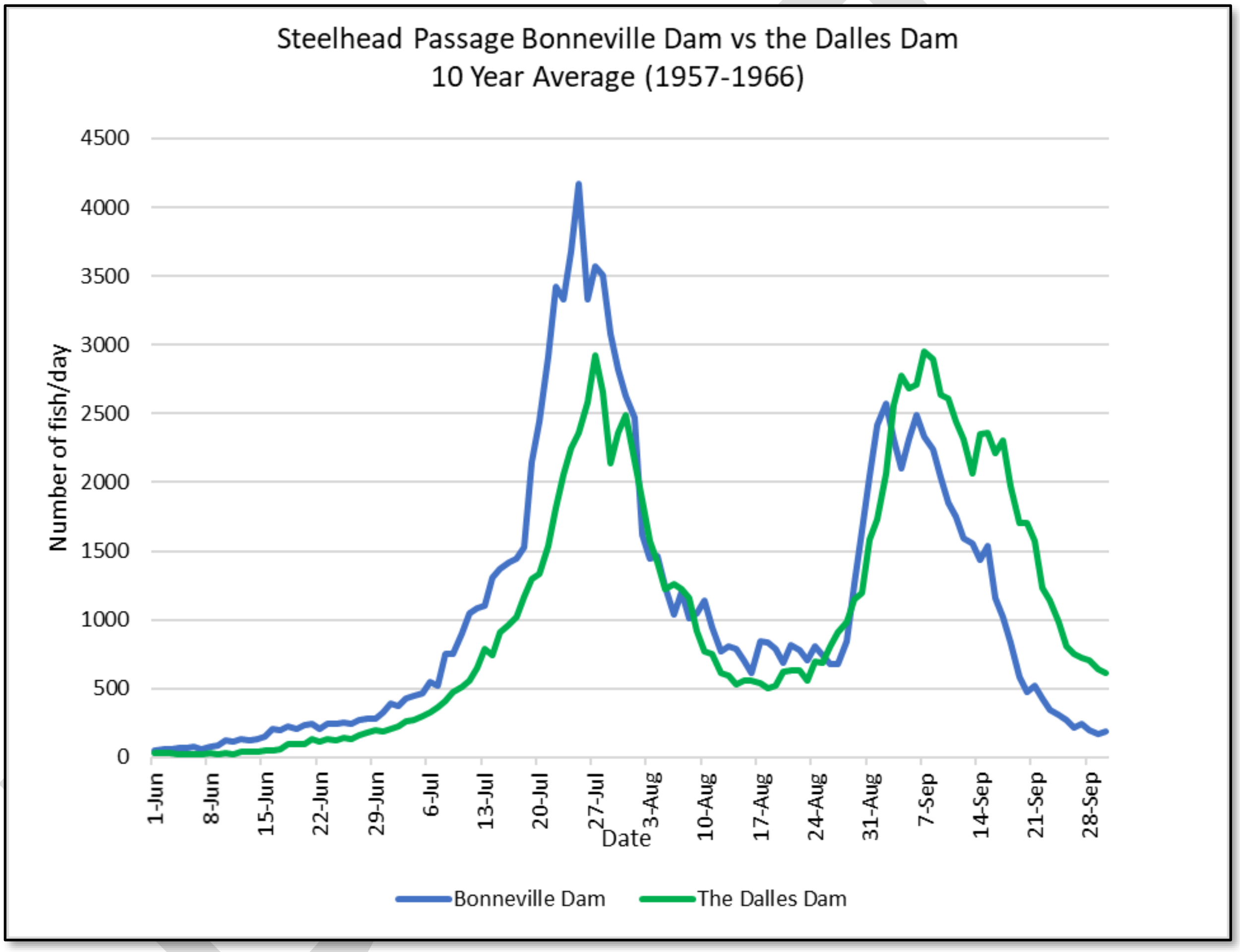


Figure 3-13 Steelhead passage at Bonneville Dam and The Dalles Dam, 1957-1966 (DART)

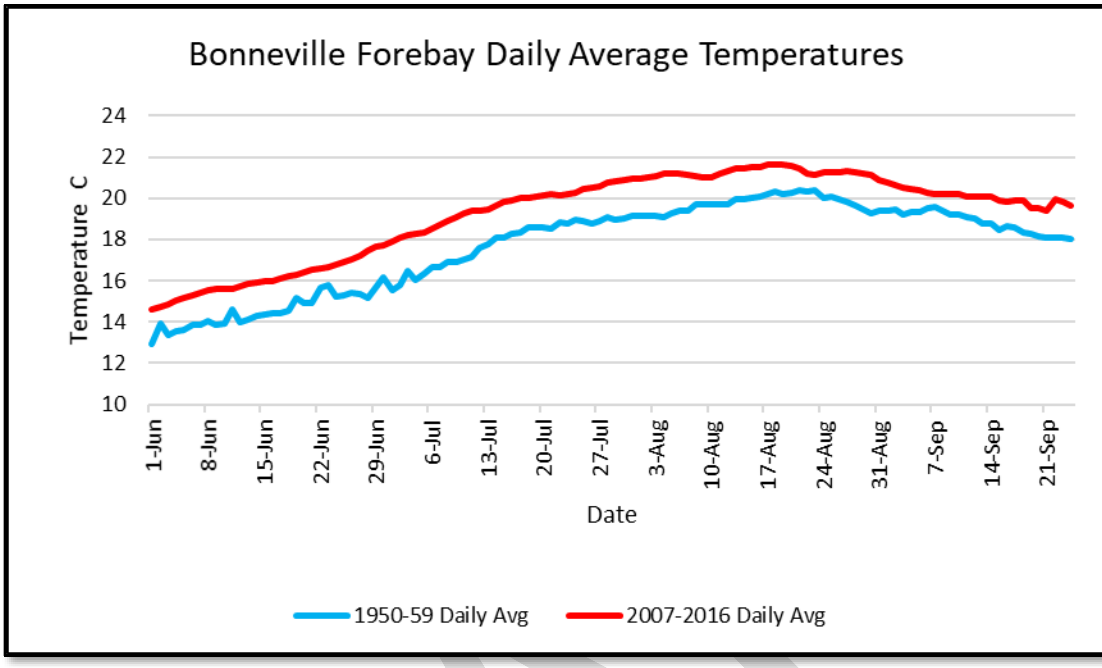


Figure 3-14 Current versus 1950s water temperatures in the Lower Columbia River (DART)

3.8 DESCHUTES RIVER COLD WATER REFUGE USE

The discussion above in Sections 3.4 – 3.7 characterizes the use of CWR by steelhead and fall Chinook in the Bonneville reach between Bonneville Dam and The Dalles Dam. Upstream of The Dalles Dam, the only other significant and primary CWR in the Lower Columbia River is the Deschutes River. The Deschutes River is unique in that it has a PIT-tag detector, installed in 2013 near the mouth, which NOAA Fisheries has used to analyze the extent that steelhead use the Deschutes River for CWR (NOAA 2017a). ***Table 3-5*** shows that an average of 873 PIT-tagged steelhead were recorded in Deschutes River CWR comprised mostly of Snake River (61%) and Middle Columbia steelhead (30%).

Table 3-5 Deschutes River mouth steelhead PIT-tag detections by calendar year and Distinct Population Segment (DPS) (NOAA 2017a)

DPS	2013	2014	2015	Average	%
Lower Columbia	9	5	31	15	2%
Middle Columbia	174	214	385	258	30%
Snake River	541	506	540	529	61%
Upper Columbia	74	54	86	71	8%
Total	798	779	1042	873	

Table 3-6 shows the number of Snake River PIT-tagged steelhead detected at The Dalles Dam and the percentage of those steelhead detected at the Deschutes River mouth. Approximately 14% (12-18%) of the Snake River (SR) steelhead detected at The Dalles Dam were recorded in the Deschutes River mouth. Applying the ratio of PIT-tagged SR steelhead to the total number of steelhead passing The Dalles Dam, ***Table 3-6*** shows that the estimated total number of SR steelhead using Deschutes River CWR in an average year is 27,659 (NOAA 2017a). Assuming 61% of all steelhead in Deschutes River CWR are SR steelhead, the total number of steelhead using the Deschutes River CWR in an average year is 45,343.

Table 3-6 Percent of Snake River steelhead using Deschutes cold water refuges and number of steelhead using Deschutes cold water refuges (NOAA 2017a)

	SR PIT tagged Steelhead Detected @ Dalles Dam	% of SR PIT tagged Steelhead Detected at Deschutes	Estimated Number of Total SR Steelhead in Deschutes CWR	Estimated Number of All Steelhead in Deschutes CWR
2013	2977	18%	26,162	42,889
2014	4201	12%	30,332	49,725
2015	3279	13%	26,483	43,415
Average	3486	14%	27,659	45,343

Figure 3-15 shows how many SR steelhead are estimated to be within Deschutes River CWR for each month. As depicted in ***Figure 3-15***, the peak period of use was September in 2013 and 2014 and in August in 2015. During this peak period of use, approximately 10,000 to 16,000 SR steelhead were in the Deschutes River CWR. Assuming 61% of all steelhead in Deschutes River CWR are SR steelhead, the total number of steelhead using the Deschutes River CWR during the peak period of use is 16,000 to 26,000. 26,000 steelhead in the Deschutes River CWR would equate to a density of 0.087 steelhead per square meter, which is the same upper range density estimated for Bonneville Reach CWR (based on >2°C delta volume of CWR) reflected in ***Table 3-4***.

As noted above, the overall percentage of SR steelhead that use the Deschutes River as CWR is 12-18%. In August, during peak river temperatures, the percentage rises to near 25% (NOAA 2017a). This percentage is less than the percentage of steelhead that use Bonneville Reach CWR, which is about 85% during peak temperatures. There are several possible reasons for this lower percentage of use of the Deschutes River: 1) the percent of steelhead using the Deschutes River reported here does not capture use of the Deschutes plume only; 2) the Deschutes River is just one CWR on one side of the river and the Bonneville Reach CWR consists of 7 primary CWR; and 3) steelhead are encountering the Deschutes River after many have already spent time in CWR in the Bonneville Reach and later in the summer as the Lower Columbia River begins to cool. Nonetheless, the Deschutes River is a heavily used CWR and is the only primary CWR between The Dalles Dam and McNary Dam.

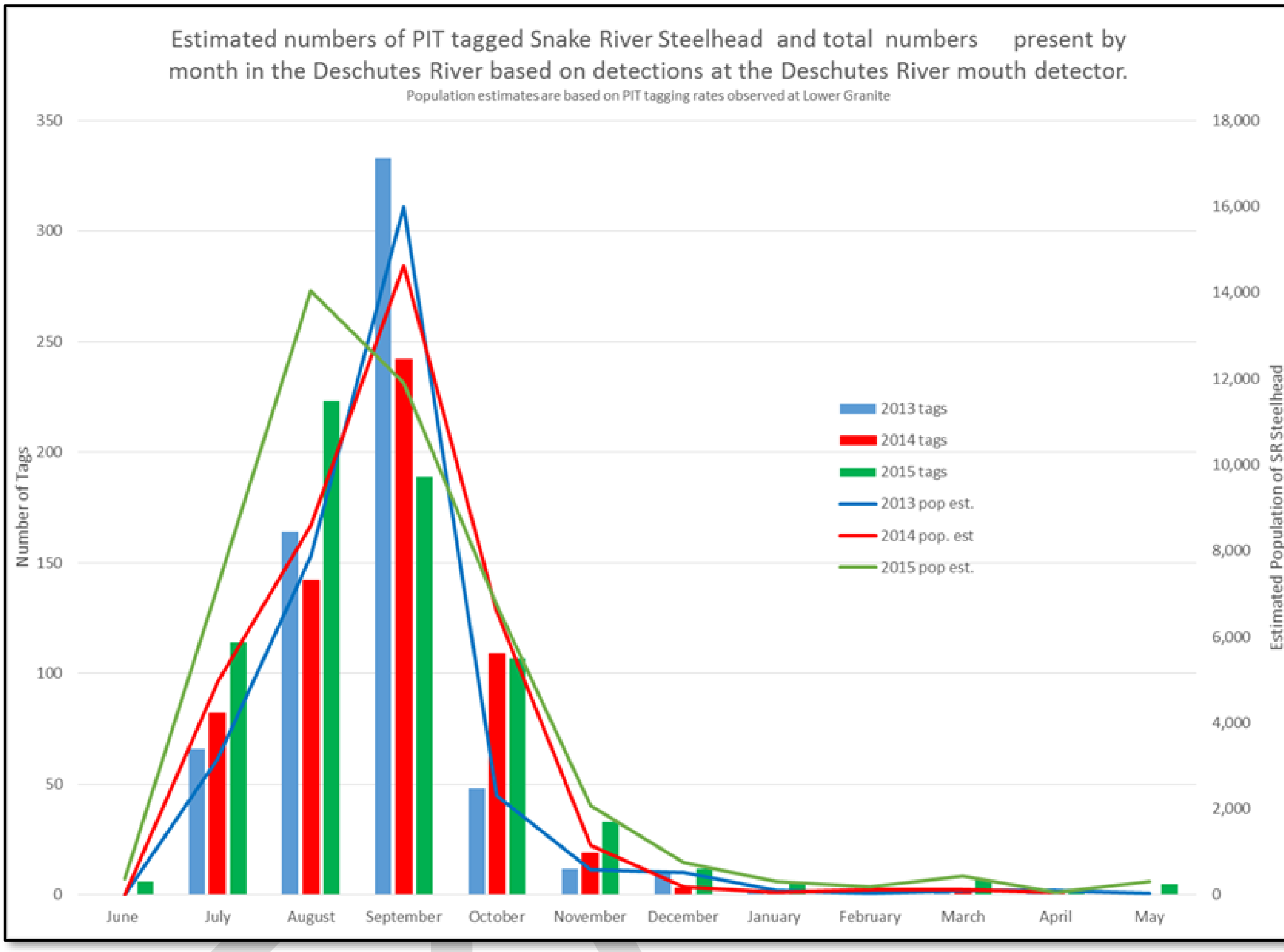


Figure 3-15 Estimated number of PIT-tagged Snake River steelhead and estimated total number of Snake River steelhead (estimated by tag expansion) present in Deschutes River cold water refuges by month 2013-2015 (NOAA 2017a)

3.9 USE OF CWR BY SPECIFIC POPULATIONS OF STEELHEAD AND FALL CHINOOK

The specific populations of steelhead and fall Chinook that use CWR the most are those with run timing that coincides with the warmest Columbia River temperatures. ***Figure 3-16*** shows the percent of specific steelhead populations that use CWR (solid circles and x-axis) and the populations' median passage time (y-axis), which reflect how long individuals from each population spend in CWR. Those steelhead populations in the upper right in ***Figure 3-16*** use CWR extensively while those populations in the lower left use CWR less. ***Figure 3-17*** shows the migration timing for the various steelhead populations, which shows that those steelhead populations with high CWR use are those where a high proportion of the population migrates through the Lower Columbia River when temperatures are warmest (i.e., late July through late August as reflected in the shaded area). Steelhead populations from the John Day, Umatilla, Grande Ronde, Imnaha, Yakima, Snake, Salmon, and Walla Walla all use CWR to a significant extent. The steelhead populations that use CWR the least are those that mostly migrate through the Lower Columbia River before (Tucannon, Hanford, and Lyons Ferry) or after (Clearwater) the warmest temperatures.

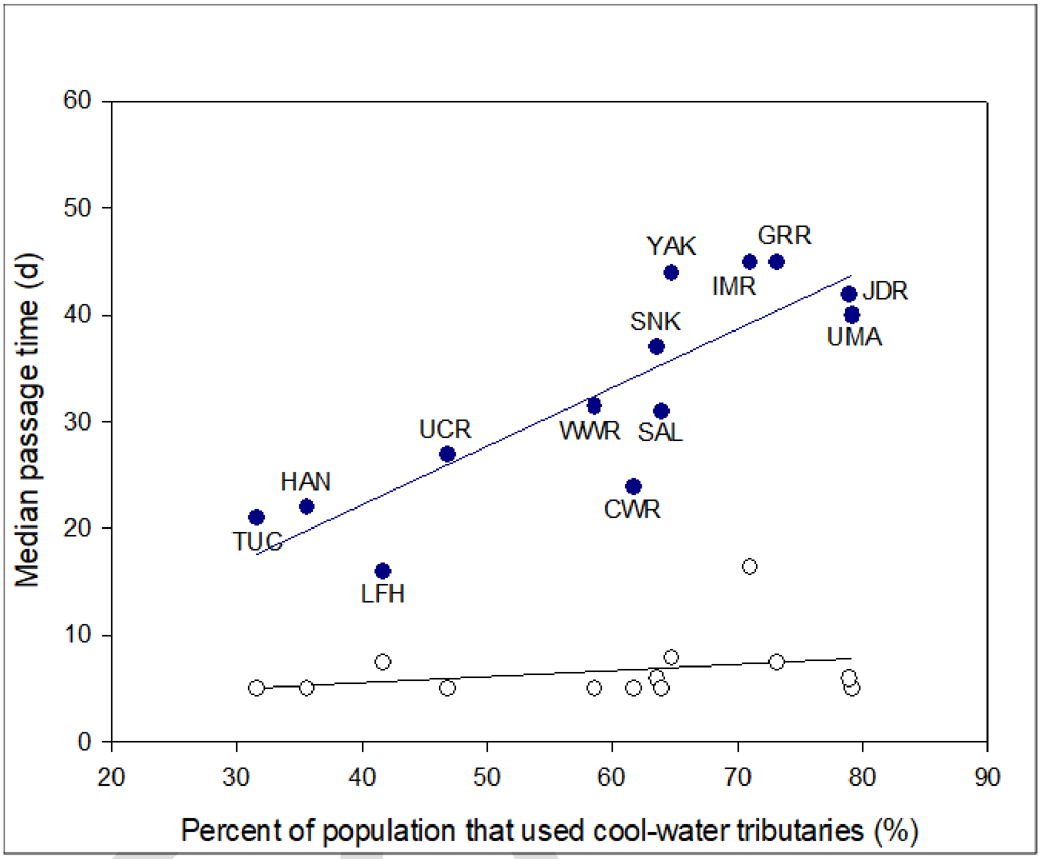


Figure 3-16 Percent of population-specific steelhead that used cold water refuges for >12 hours (solid circles) and associated median passage time from Bonneville Dam to the John Day Dam for those that used and did not use (clear circles) CWR. TUC, Tucannon River; HAN, Hanford Reach; LFH, Lyons Ferry Hatchery; UCR, Upper Columbia River; WWR, Walla Walla River; CWR, Clearwater River; SAL, Salmon River; SNK, Snake River above Lower Granite Dam; YAK, Yakima River; IMR, Imnaha River; GRR, Grande Ronde River; UMA, Umatilla River; JDR, John Day River. (Keefer et al. 2009)

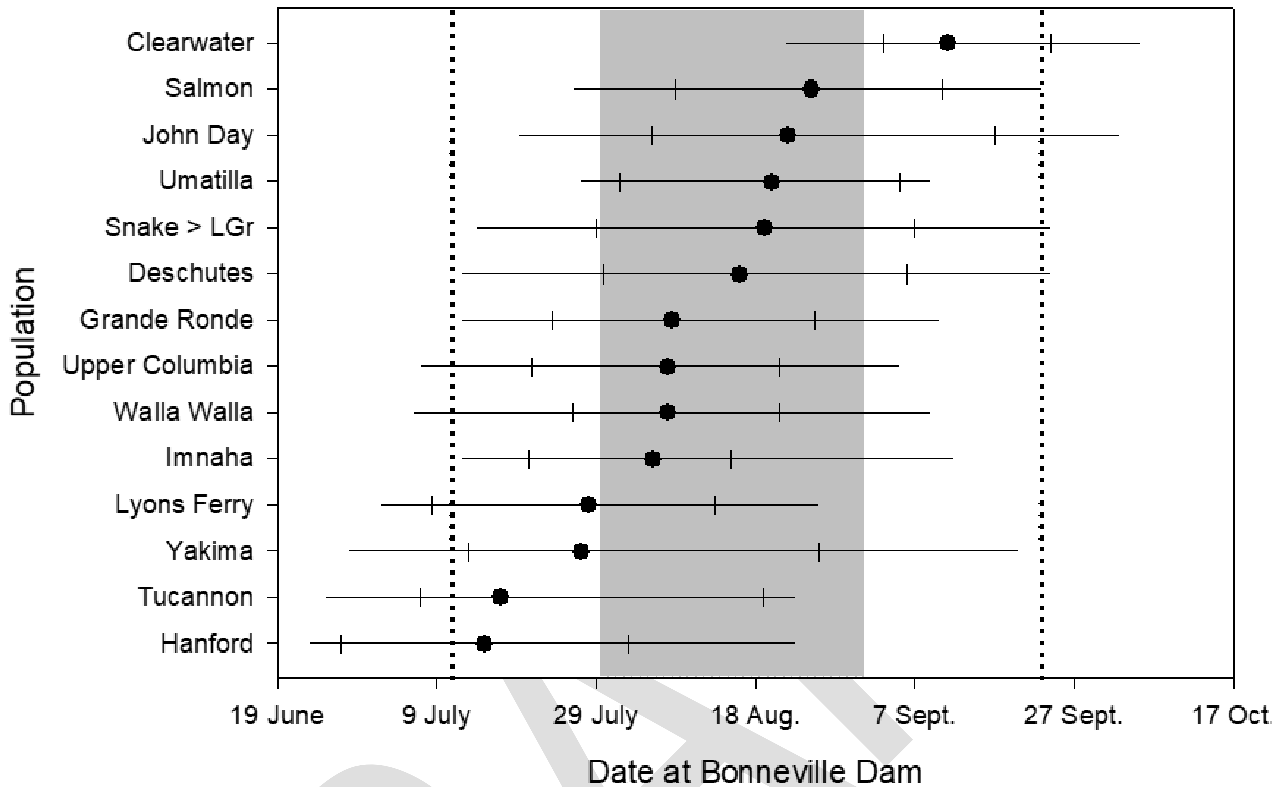


Figure 3-17 Median timing distributions (median, quartiles, and 10th and 90th percentiles) at Bonneville Dam for steelhead that successfully returned to tributaries or hatcheries. Vertical dotted lines show mean first and last dates that Columbia River water temperatures were 19°C; the shaded area shows dates with mean temperatures ≥21°C. (Keefer et al. 2009)

Similarly, those populations of fall Chinook that migrate through the Lower Columbia River in August and early September use CWR the most. ***Figure 3-18*** depicts the composition of the fall Chinook run by date. Fall Chinook are classified as Chinook that pass Bonneville Dam after August 1st. Radio-tag studies of fall Chinook use of CWR mirrors the composition of different fall Chinook populations migrating past Bonneville Dam in August and early September. Hanford reach fall Chinook and fall Chinook populations above Priest Rapids Dam were most predominately in CWR, with lesser numbers of Snake River and Yakima fall Chinook (US Army Corps, 2013). It should be noted, however, that the data in ***Figure 3-18*** is from 1998 and the early 2000s and the composition of the fall Chinook populations may be different today. In particular, the Snake River fall Chinook population has increased, so today we might expect a higher proportion of Snake River fall Chinook using CWR.

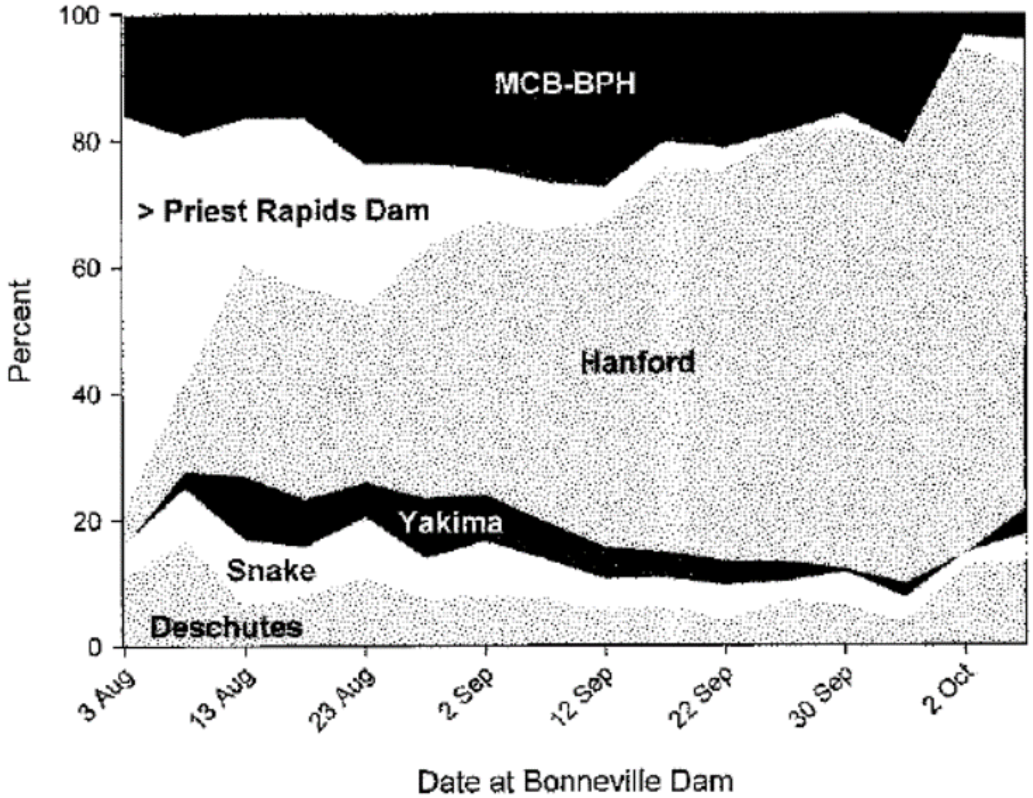


Figure 3-18 Mean composition of upriver bright fall-run Chinook salmon at Bonneville Dam using five-day intervals based on release dates of radio-tagged fish. 1998 and 2000-2004. MCB-BPH = mid-Columbia River bright-Bonneville Pool hatchery stock. (Jepson et al. 2010)

4 TEMPERATURE AND FISH HARVEST IMPACTS ON MIGRATING SALMON AND STEELHEAD

4.1 ADVERSE TEMPERATURE EFFECTS TO MIGRATING ADULT SALMON AND STEELHEAD

Water temperatures significantly affect salmon and steelhead health and survival, since they are ectothermic (cold-blooded) with their internal body temperature closely tracking river temperatures. They experience harmful health effects when exposed to warm water temperatures above their optimal range. Optimal temperatures for migrating adult salmon and steelhead are in the 12-16°C range with minimal adverse effects below 18°C (EPA 2003). Both the States of Oregon and Washington have a 20°C maximum water quality criteria for the Lower Columbia River, which is consistent with EPA's recommended criteria for large mainstem rivers that naturally warm to this level and are used by salmon and steelhead for migration (EPA 2003).

Table 4-1 summarizes the adverse effects to migrating adult salmon and steelhead in the Lower Columbia River as temperatures rise above 18°C. The temperature ranges in ***Table 4-1*** represent average river temperatures. In general, as temperatures rise, disease risk, stress, energy loss, avoidance behavior, and mortality rates increase. Sockeye are most susceptible to warm temperatures with limited mortality at 19-20°C and significant mortality at 20-21°C. Steelhead are also susceptible to these temperature ranges but exhibit avoidance behavior by seeking cold water refuges (CWR) as is demonstrated in this plan. Chinook are more tolerant to warm temperatures, with avoidance behavior (seeking CWR) and mortality occurring at higher temperatures (21-22°C and higher).

In other portions of this plan, documented research on the effects summarized in ***Table 4-1*** is provided, specifically Chapter 2 related to avoidance behavior and CWR use and sections 4.2, 4.5, and 4.6 related to mortality, energy loss, and shifts in migration timing.

Table 4-1 Summary of temperature effects to migrating adult salmon and steelhead in the Lower Columbia River (EPA 2003; McCullough 1999, Richter and Kolmes 2005)

Temperature Range	Effects
Less than 18°C	• Minimal effects to salmon and steelhead
18-20°C	• Elevated disease risk • Low proportion of steelhead seek CWR • Slight increase in sockeye mortality
20-21°C	• Significant disease risk • Increased stress and energy loss • Majority of steelhead seek CWR • Significant sockeye mortality • Low proportion of Chinook seek CWR
21-22°C	• High disease risk • High stress and energy loss • High percentage of steelhead move into CWR • Very high sockeye mortality • Moderate proportion of Chinook seek CWR
22-23°C	• Very high disease risk • Very high stress and energy loss • Very high percentage of steelhead move into CWR • Near complete sockeye mortality • Significant proportion of Chinook seek CWR
23-24°C	• Very high disease risk • Very high stress and energy loss • High avoidance behavior for steelhead and all salmon • High mortality for steelhead and salmon species

4.2 RELATIONSHIP BETWEEN TEMPERATURE AND MIGRATION SURVIVAL OF ADULT STEELHEAD AND FALL CHINOOK SALMON

The survival rates of migrating adult salmon and steelhead between Bonneville Dam and McNary Dam can be estimated by comparing the passage counts at each of the dams. The Fish Passage Center conducted an analysis of the survival rates between these two dams as a function of Columbia River water temperature. ***Figure 4-1*** shows that the survival rate for steelhead (PIT-tagged 2003-2015) decreases at 18°C temperatures and higher, and there is about a 10% reduction in survival at 21-22°C temperatures compared to 18°C and below temperatures. ***Figure 4-2*** shows the survival rates for fall Chinook at three different temperature ranges (below 20°C, 20-21°C, and >21°C) with a decline in survival with warmer temperatures. There is approximately a 7-8% decrease in survival for temperature >21°C versus below 20°C. ***Figure 4-2*** also shows that adults that were transported in barges down the Columbia River as juveniles have less survival than those that migrated downstream in the Columbia River.

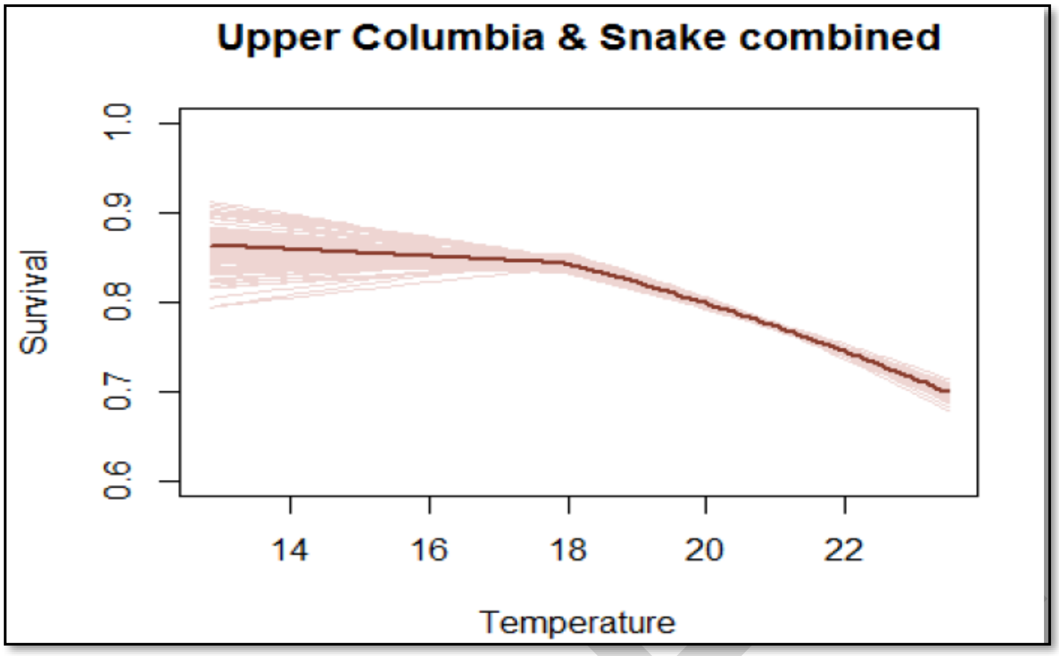


Figure 4-1 Estimated survival rate of adult steelhead between Bonneville Dam and McNary Dam (FPC, October 31, 2016 Memo)

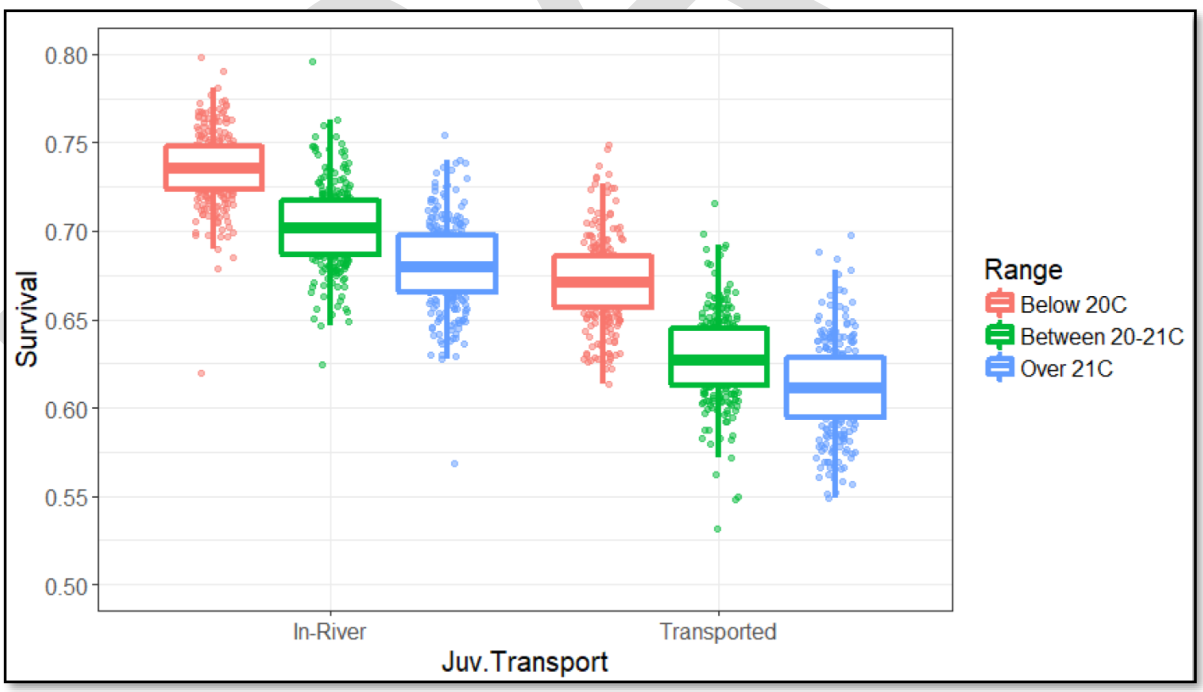


Figure 4-2 Estimated survival rate of adult fall Chinook between Bonneville Dam and McNary Dam (FPC, May 8, 2018 Memo)

The results shown in ***Figure 4-1*** and ***Figure 4-2*** indicate that the migration survival of an individual steelhead or a fall Chinook salmon between Bonneville Dam and McNary Dam decreases by 7-10% as temperatures rise above 21°C. It should be noted that other factors, such as increased harvest of fish that moved into CWR due to the rise in temperature, could be contributing to the decreased survival rates.

4.3 FISHING HARVEST OF SALMON AND STEELHEAD IN COLD WATER REFUGES

As noted above in Section 4.2, the correlation between increased Columbia River temperature and decreased migration survival of adult steelhead and fall Chinook in the Lower Columbia River could also be associated with increased fishing harvest in CWR at warmer Columbia River temperatures. Fishing harvest in CWR also makes it difficult to directly measure the benefits of CWR to migrating adult salmon and steelhead.

Keefer et al. (2009) analyzed the migration success of steelhead that used CWR versus those that did not use CWR. This study found that migration success to the spawning tributaries for those steelhead (wild and hatchery) that used CWR was about 8% less than those steelhead that did not use CWR, which initially suggests CWR use is not beneficial. However, the study also indicated that fishing harvest in CWR explained the decreased survival. Wild steelhead using CWR, which are required to be released when caught, experienced a 4.5% decrease in survival during migration to their spawning tributaries compared to wild steelhead that did not use CWR. This increased mortality, however, could be associated with catch and release mortality and incidental catch of wild steelhead in CWR.

NOAA (2017) also found that the survival rate for steelhead (wild and hatchery) from The Dalles Dam to McNary Dam was about 9% less for those steelhead that used CWR (detected in the Deschutes River) versus those that did not use CWR. NOAA's assessment also provided data on fish harvest in the Deschutes River that explained the reduced survival for those steelhead using CWR.

Due to fishing harvest in CWR, it is difficult to directly measure the extent to which steelhead and fall Chinook CWR use may lead to higher migration survival rates due to avoidance and minimization of exposure to warm Lower Columbia River temperatures. Similarly, it is difficult to separate how much of the observed 7-10% decrease in steelhead and fall Chinook survival in the Lower Columbia River when temperatures exceed 21°C is due to temperature effects versus fishing harvest. More sophisticated studies, perhaps during periods with no fishing, would likely be needed to accurately answer these questions quantitatively.

4.4 SNAKE RIVER STEELHEAD AND FALL CHINOOK MIGRATION SURVIVAL RATES IN THE LOWER COLUMBIA AND LOWER SNAKE RIVERS

Section 4.2 assessed the impact that river temperatures have on the survival rate of individual steelhead and fall Chinook. This section looks at the survival rate in the Lower Columbia River for ESA-listed Snake River steelhead and fall Chinook runs to ascertain if elevated temperatures may be contributing to decreased survival rates. NOAA Fisheries calculates the survival rates of ESA-listed salmon and steelhead in the Lower Columbia River each year for the whole run. As shown in ***Figure 3-17*** and ***Figure 3-18*** above, the Snake River steelhead run passes Bonneville Dam from July through September, and the Snake River fall Chinook run passes Bonneville Dam from August through early October, respectively. Thus, a portion of these runs migrate through the Lower Columbia River when water temperatures exceed 20°C, while a portion of the runs migrate through when temperatures are below 20°C.

Figure 4-3 shows the "adjusted" survival rate for Snake River steelhead between Bonneville Dam and McNary Dam and between Bonneville Dam and Lower Granite Dam on the Snake River for each year (2008-2017). "Adjusted" denotes the survival rate, factoring in the estimated percentage that are harvested or stray. Therefore, adjusted survival highlights the percentage that does not survive for unknown reasons. As shown in ***Figure 4-3***, the ten-year average adjusted survival rate from Bonneville Dam to McNary Dam is 94% (range of 90 to 100%) and from Bonneville Dam to Lower Granite Dam is 87% (range 81 to 94%). These data indicate that there is 6% unexplained mortality of adult Snake River steelhead migrating between the Bonneville and McNary Dams and an additional 7% unexplained mortality between McNary Dam and Lower Granite Dam. Part of this unexplained mortality is likely attributable to mortality associated with prolonged exposure to Columbia River temperatures above 20-21°C during the upstream migration as has been observed to occur per ***Figure 4-1*** above. Absent detailed studies, this 6% migration mortality rate appears to be equal for hatchery and wild steelhead. For context, the estimated Snake River steelhead harvest (primarily for hatchery steelhead) between Bonneville Dam and McNary Dam (Zone 6) is approximately 15%, and the estimated stray rate is 5%.

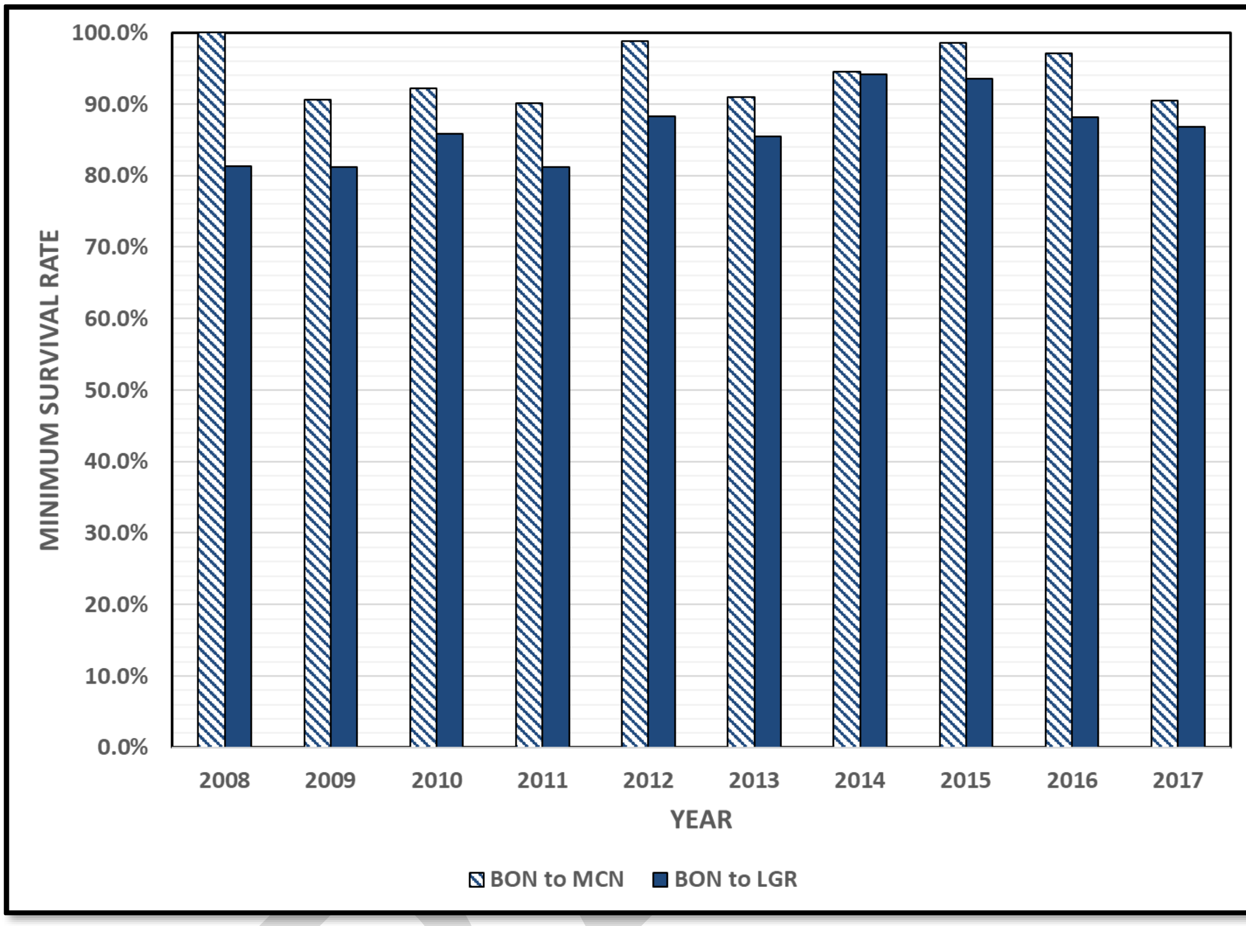


Figure 4-3 Adjusted survival estimates of adult Snake River steelhead between Bonneville Dam (BON) and McNary Dam (MCN) and between Bonneville Dam and Lower Granite Dam (LGR) for the whole run (NOAA, 2019)

Figure 4-4 shows the “adjusted” survival rate for the Snake River fall Chinook run between Bonneville Dam and Lower Granite Dam for each year (2008-2016). The average adjusted survival for Snake River fall Chinook between Bonneville Dam and Lower Granite Dam is 90%, which means there is 10% unexplained mortality of adult Snake River fall Chinook migrating between the two dams. About half (5%) of this mortality occurs between Bonneville Dam and McNary Dam, and half (5%) occurs between McNary Dam and Lower Granite Dam and likely is the same rate for both hatchery and wild Snake River fall Chinook. In some years, the survival rate is 80% with 20% unexplained mortality (2011, 2013, 2016) between Bonneville Dam and Lower Granite Dam. Part of this unexplained mortality is likely associated with prolonged exposure to Columbia River temperatures above 21°C during the upstream migration as has been observed to occur per ***Figure 4-2*** above. For context, the estimated Snake River fall Chinook harvest rate (primarily for hatchery fall Chinook) between Bonneville Dam and McNary Dam (zone 6) is approximately 23%, and the estimated stray rate is 3%.

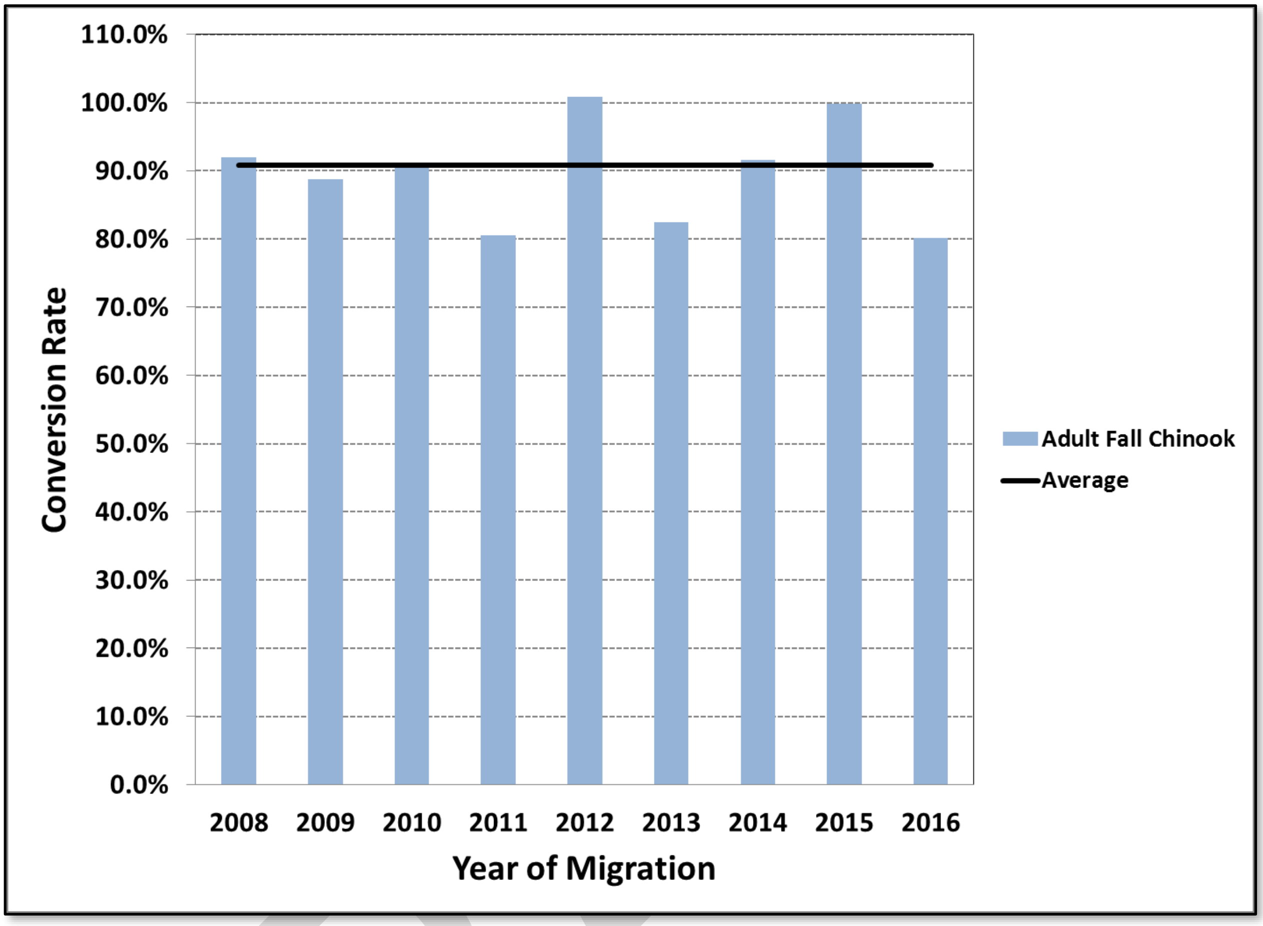


Figure 4-4 Adjusted survival estimates of adult Snake River fall Chinook between Bonneville Dam and Lower Granite Dam for the whole run (NOAA, 2019)

The information summarized above in this section and in Section 4.2 indicates exposure to warm Lower Columbia (and Snake River) temperatures is likely contributing to mortality loss of migrating adult steelhead and fall Chinook salmon. However, in NOAA's Biological Opinion (2019) on the operations of the Columbia River System, NOAA concluded these losses under current conditions are not substantially impairing the recovery of ESA-listed Snake River steelhead and fall Chinook. As noted elsewhere, use of CWR by these species may be aiding their migration through the Lower Columbia during periods of warm temperatures.

4.5 ENERGY LOSS AND PRE-SPAWNING MORTALITY OF FALL CHINOOK SALMON FROM EXPOSURE TO WARM MIGRATION TEMPERATURES

As described in Section 4.1, prolonged exposure to warm river temperatures can have adverse effects on migrating salmon. The rate of energy expenditure as a fish migrates is directly dependent on swimming speed (fish speed plus water velocity) and temperature (Connor et al. 2018). For a fish to successfully spawn at the end of its migration, it must have enough energy reserves left to allocate to gonad formation and complete the spawning process. A 2018 study by Plumb uses a bioenergetics model to examine the effects of temperature on migration energy use and spawning success. The study focuses on Snake River fall-run Chinook migrating from Bonneville Dam in the Columbia River to the confluence of the Snake and Salmon rivers in Hells Canyon.

Based on previous studies (Bowerman et al. 2017), Plumb defined the energy threshold criterion for successful spawning as 4 kJ/g, where fish below this threshold typically die and do not successfully spawn. Migrating salmon have finite energy reserves at the start of their migration, and high river temperatures can hasten the rate at which fish reach this physiological threshold, ultimately limiting spawning success (Plumb 2018).

Increases in time spent and distance traveled during migration lead to increases in pre-spawning mortality, supporting a link between energy expenditure and spawning success (Bowerman et al. 2017). Annual detections of PIT-tagged fish validate that slower travel rates and greater exposure to higher temperatures affect arrival probabilities at spawning grounds. The probability of fall Chinook having sufficient (>4 kJ/g) energy reserves to spawn depends in part on two factors: (1) day of the year a fish migrates from Bonneville Dam; and (2) whether a fish uses CWR during migration. While early fall Chinook migrants are exposed to warmer temperatures in comparison to later migrants, using CWR as a coping strategy can influence the amount of energy reserves a fish has at time of spawning. Holding in CWR and migrating later when Columbia and Snake River temperatures are lower can reduce thermal exposure and energy loss.

Plumb (2018) modelled the thermal experience of simulated fall Chinook, which was a function of the mainstem river temperatures during migration (Columbia and Snake Rivers), the temperature difference between the mainstem river and a cold water tributary, and the probability of a fish occupying a cold water tributary.

Figure 4-5 demonstrates that simulated fish using CWR experienced lower cumulative temperatures and energy loss, which increased the proportion of early migrants surviving to spawn. For instance, among fall Chinook migrating in August, those that used CWR (light grey line) had a higher proportion with sufficient energy to complete spawning than those that did not (dotted line).

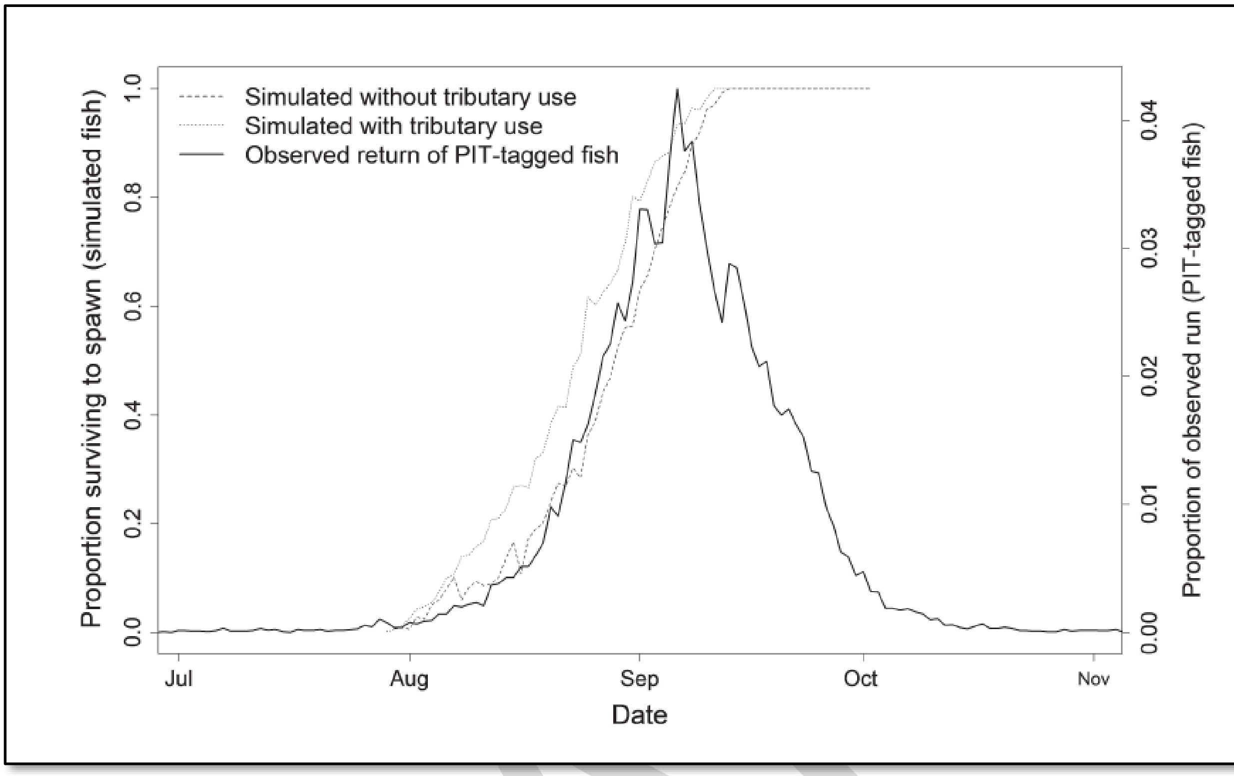


Figure 4-5 The proportion of simulated fish that had energy densities greater than the 4 kJ/g threshold needed for sufficient energy to spawn (Plumb, 2018)

Supporting Plumb's findings, ***Figure 4-6*** (Connor et al. 2018) shows that the early portion of the spawning distribution of fall Chinook is predicted to drop below the energy threshold needed for successful spawning and experience pre-spawning or premature mortality.

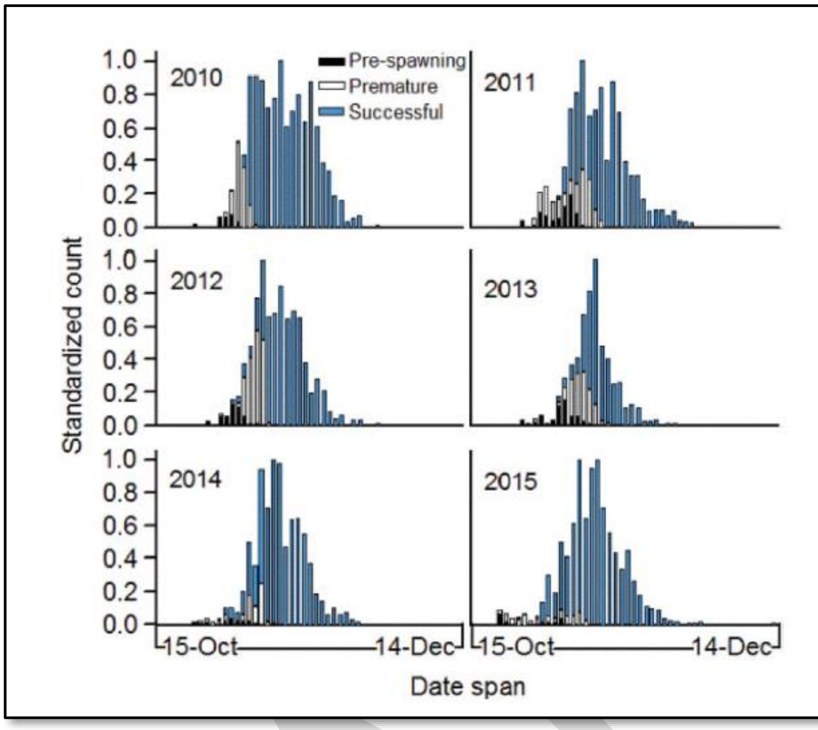


Figure 4-6 Standardized, simulated spawning initiation date distributions for PIT-tagged, hatchery-origin Snake River fall Chinook salmon adults, 2010-2015 (Conner et. al 2018)

Under simple temperature increases of 1, 2, and 3°C from baseline river temperatures to mimic future conditions with climate change, there was a linear decline in the median energy remaining at spawning and in the fraction of simulated fish having enough energy reserves to spawn (Plumb 2018). As average temperatures increased, Chinook who did *not* utilize CWR were forced to migrate later in the year from Bonneville Dam to have enough energy reserves left to spawn. However, for Chinook that *did* utilize CWR during migration under increasing river temperatures, passage dates from Bonneville Dam were on average 18-27 days earlier than fish that did not utilize CWR. This finding supports the conclusion that using CWR during upriver migration may provide early migrants with an energetic advantage over fish that do not use them. Further, the proportion of fish that seek and use thermal refuge is likely to increase as temperature increases (Connor et al. 2018).

4.6 INCREASED MORTALITY AND SHIFT IN RUN TIMING OF SOCKEYE AND SUMMER CHINOOK FROM WARM MIGRATION TEMPERATURES

As noted earlier, sockeye salmon do not appear to use CWR to avoid warm Lower Columbia River temperatures, and it does not appear to be advantageous to do so. Sockeye salmon migrate through the Lower Columbia River in June and July prior to the warmest summer river temperatures that typically occur in August. If sockeye salmon were to delay their migration by entering CWR, they would end up encountering warmer Columbia River temperatures during their continued upstream migration.

Warm Lower Columbia River temperatures, however, do have a significant impact on sockeye salmon. The unusually warm June and July Lower Columbia River temperatures that occurred in 2015 illustrate the relationship between warmer river temperatures and increased mortality of sockeye salmon. As shown in ***Figure 4-7***, in 2015 Lower Columbia river temperatures were significantly warmer than average during the June-July sockeye run, reaching 20°C (68°F) at the peak of the run, in late June. Typically, temperatures are about 16°C (61°F) during the peak of the sockeye run in late June.

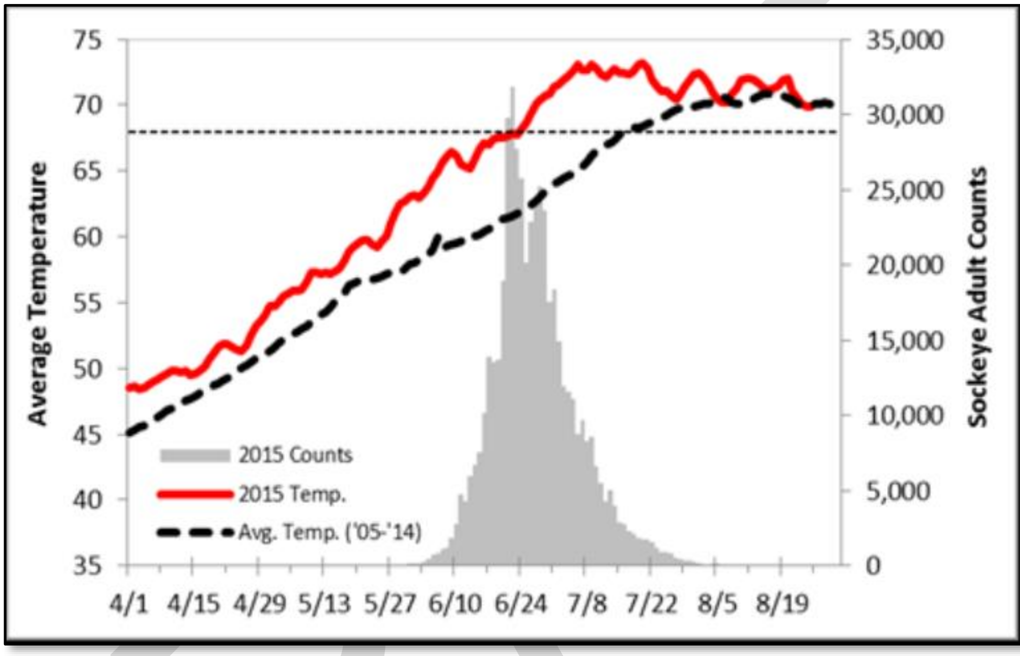


Figure 4-7 Sockeye passage and river temperature at Bonneville Dam (FPC, August 26, 2015 Memo)

Figure 4-8 shows how survival of sockeye from Bonneville Dam to McNary Dam dropped significantly as temperature rose during the sockeye run in 2015. In early June when river temperatures were below 19°C, survival between the two dams was high (90-100%). During week 4 in ***Figure 4-8*** (June 22–28), when river temperature climbed above 20°C, survival dropped to 70% for Columbia River sockeye and 50% for Snake River sockeye (10% for Snake River sockeye transported as juveniles). In weeks 5-8, when river temperatures exceeded 21°C, survival was very low (0-20%). Because most of the Snake River sockeye migrated in late June and July, the overall survival for Snake River sockeye between Bonneville Dam and McNary Dam was only 15% in 2015 (FPC 2015).

Although 2015's unusually warm June-July river temperatures had a dramatic effect on sockeye salmon survival in the Lower Columbia River, warm Lower Columbia River temperatures result in decreased sockeye survival in other years as well. ***Figure 4-9*** shows the sockeye survival rate between Bonneville and McNary dams as a function of river temperature across the sockeye run for six different years (2010-2015). In 2010-2012 when the sockeye migrated through the Lower Columbia River before river temperatures reached 64°F (18°C) survival rates were relatively high (approximately 75%). In 2013 and 2014, for those sockeye migrating through Lower Columbia River when temperatures exceeded 64°F (18°C) survival decreased, most dramatically for Snake River sockeye.

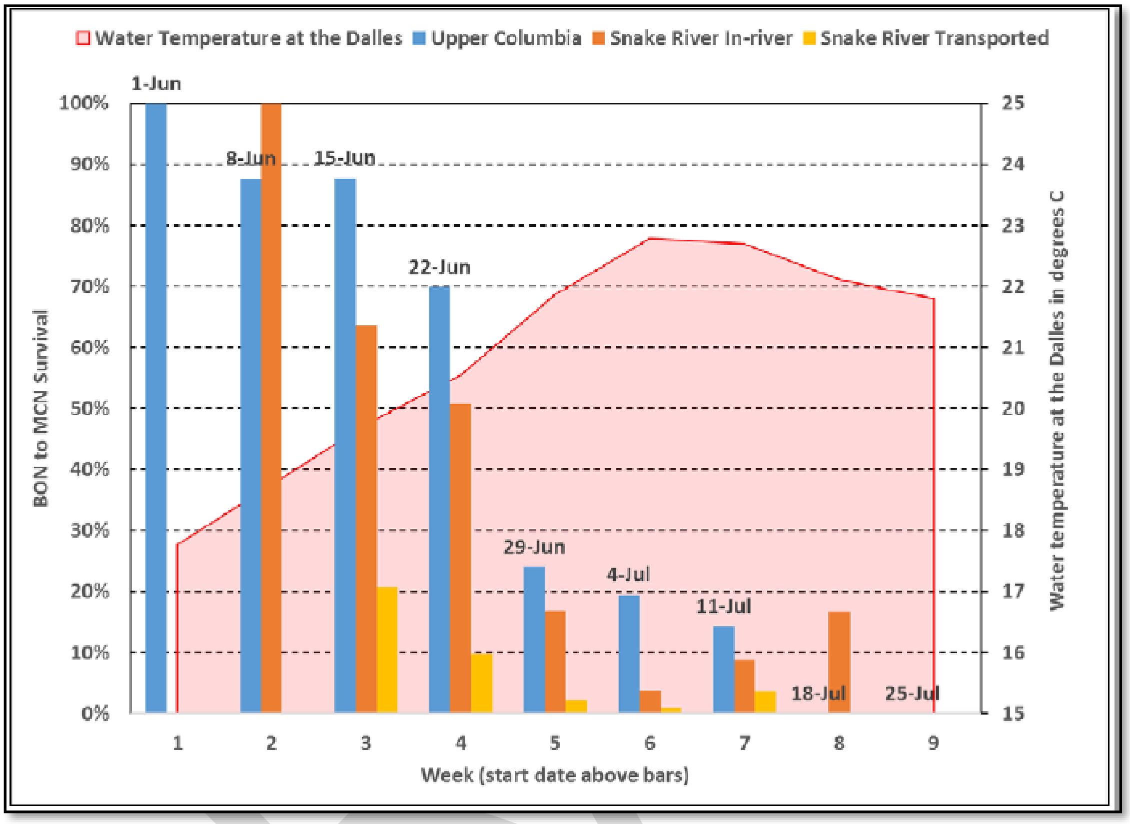


Figure 4-8 Weekly survival estimates from Bonneville Dam to McNary Dam in 2015 for Upper Columbia River Sockeye (blue bars), Snake River sockeye that migrated in-river as juveniles (orange bars), and Snake River sockeye that were transported as juveniles (yellow-orange bars) with water temperatures (red line) at The Dalles Dam (NOAA 2016)

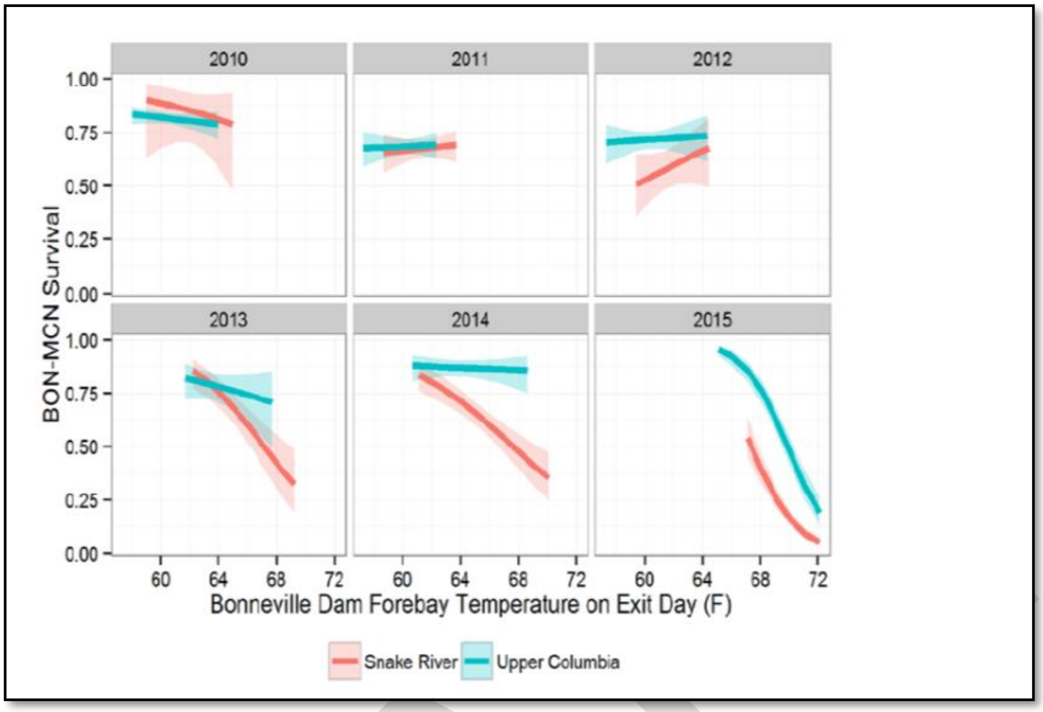


Figure 4-9 Estimated relationship between Bonneville Dam forebay temperature and Bonneville Dam to McNary Dam survival by return year for Snake and Upper Columbia adult sockeye (FPC Memo 2015)

As described in ***Figure 4-8*** and ***Figure 4-9***, July Lower Columbia River temperatures have a pronounced effect on sockeye salmon migration survival. ***Figure 4-10*** shows how increasing July river temperatures at Bonneville Dam (Panel B) over the past 60 years has resulted in earlier migration of Columbia River sockeye salmon. The median passage date, which historically was the first week of July, is now the last week of June (***Figure 4-10***, Panel A). Thus, as July river temperatures have increased, the July sockeye migrant mortality has increased. Over time, because the June sockeye migrants are more successful, the genetic traits of the June migrants increase as a percentage of the population, contributing to the shift in migration timing (Crozier et al. 2011).

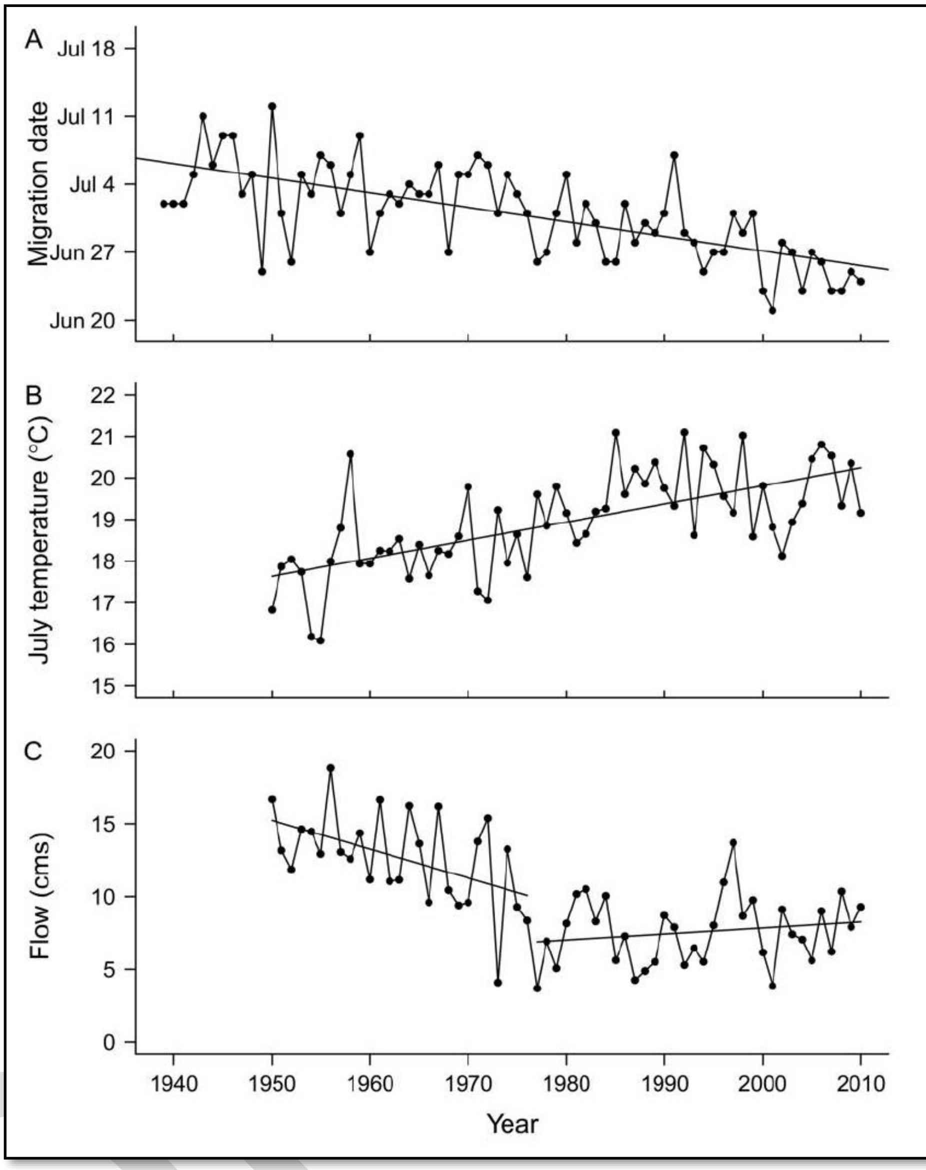


Figure 4-10 Median sockeye salmon migration date (A), July mean temperature (B), and June mean flow (C) at Bonneville Dam (Crozier et al. 2011)

Summer Chinook, like sockeye salmon, migrate through the Lower Columbia River in June and July prior to the warmest summer temperatures (***Figure 3-1***). And, for the reasons described above for sockeye salmon, summer Chinook likely do not use CWR, except for brief periods of respite. Summer Chinook also have increased adult mortality with increased temperatures. ***Figure 4-11*** shows that 2013, 2014, and especially 2015 had above normal river temperatures during the June-July migration period for Snake River summer Chinook passing Bonneville Dam. ***Figure 4-12*** shows the decreased survival rate of Snake River summer Chinook between Bonneville and McNary dams for 2013, 2014, and 2015 relative to the average survival rate (80%). The warmer-than-average temperatures in these years is likely a contributing factor to the decreased survival.

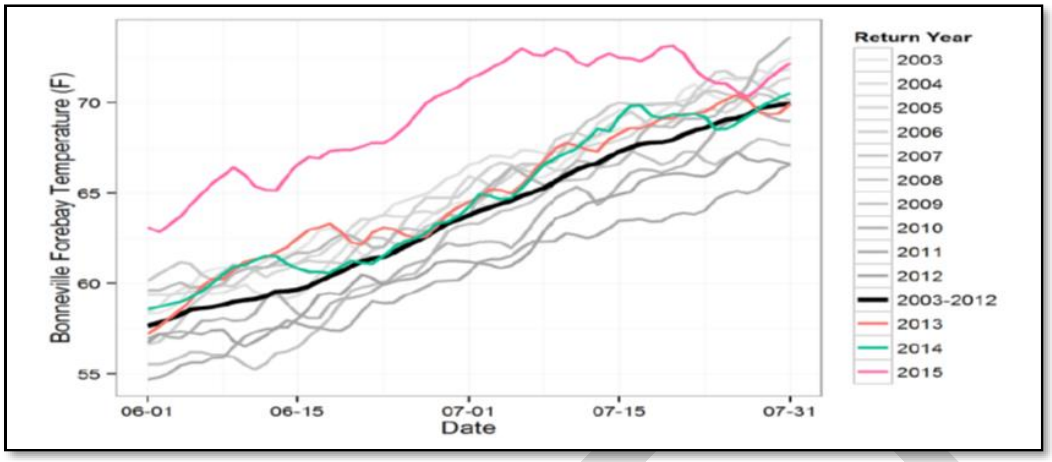


Figure 4-11 Daily average temperature (°F) in the Bonneville Dam forebay from June 1 to July 31 by return year (FPC 2016)

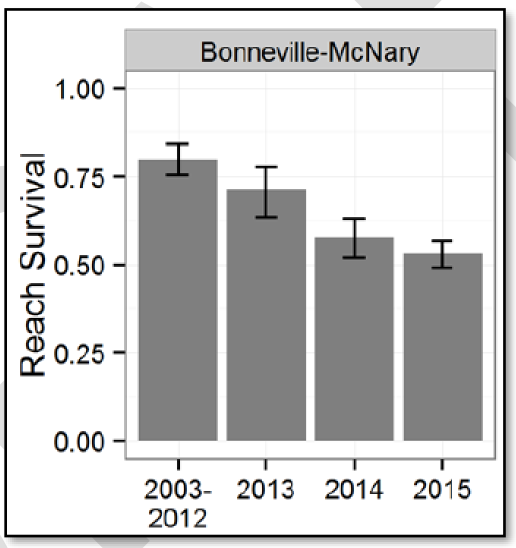


Figure 4-12 Hatchery Snake River summer Chinook adult reach survival with 95% confidence intervals by return year (FPC 2016)

Much like the sockeye salmon run, the summer Chinook run has also shifted to earlier in the year, likely in response to rising July temperatures. ***Figure 4-13*** and ***Figure 4-14*** show the distribution of the summer Chinook run over Bonneville dam from 1994 to 2018. ***Figure 4-14*** shows that both the 50% passage date (yellow line) and the 90% passage date (blue line) has shifted earlier by about 1 week over the past 25 years. Due to the increase in July temperatures in the Lower Columbia River, only a small portion (10% or less) of the summer Chinook run pass Bonneville Dam in the last two weeks of July.

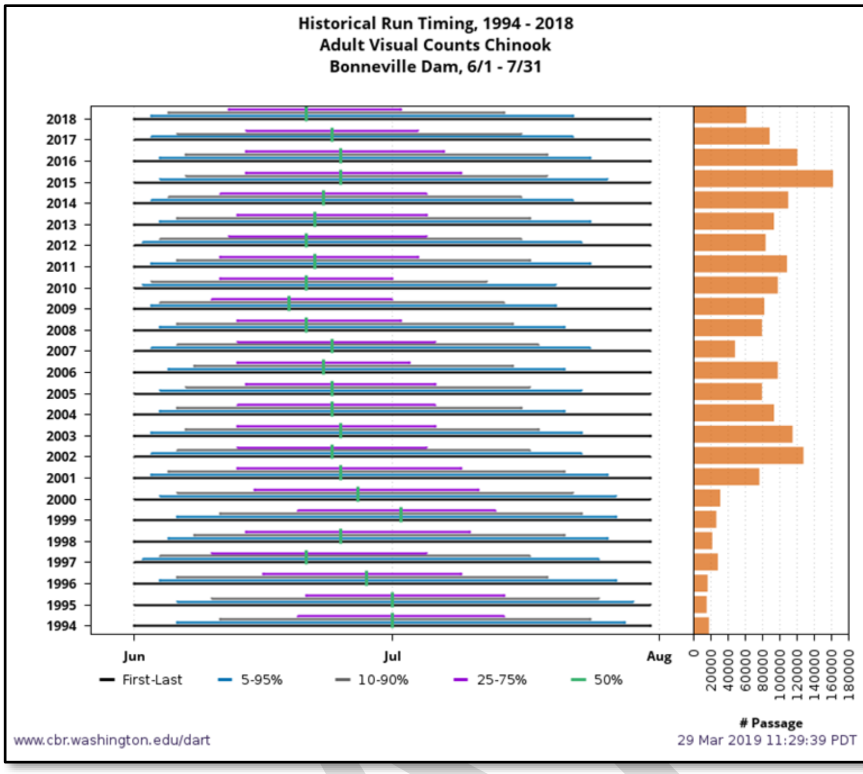


Figure 4-13 Summer Chinook run timing past Bonneville Dam (1994-2018) (DART)

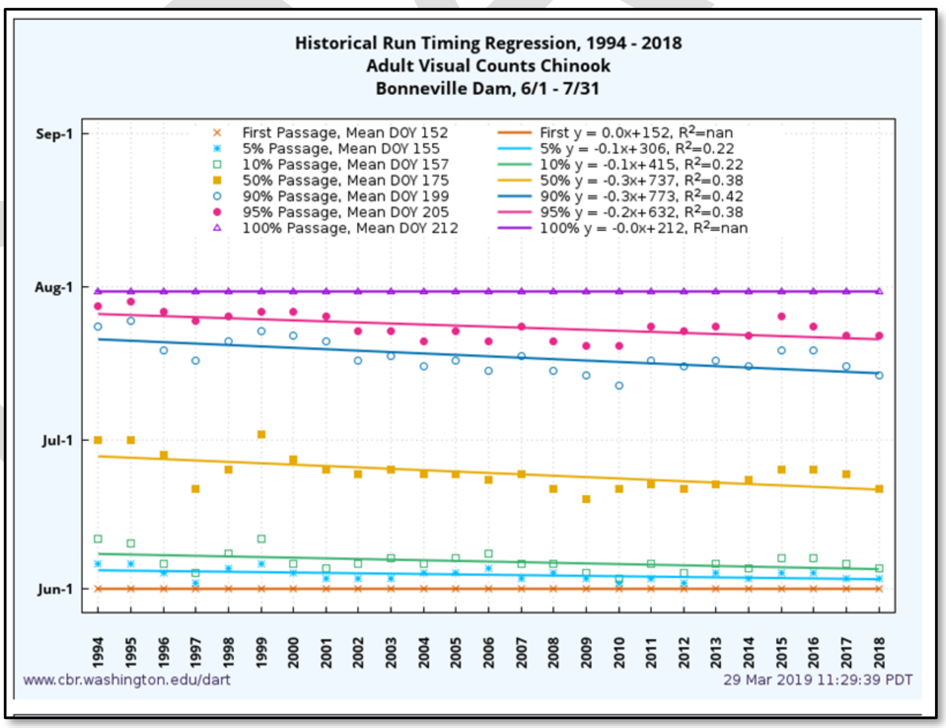


Figure 4-14 Trends in summer Chinook run distribution past Bonneville Dam (1994-2018) (DART)

5 HISTORIC AND FUTURE TRENDS IN COLUMBIA RIVER TEMPERATURES

5.1 HISTORIC TEMPERATURE CONDITIONS OF THE LOWER COLUMBIA RIVER

Based on available literature and EPA analyses (Appendix 12.16), the estimated increase in Columbia River temperatures from climate change since the 1960 baseline ranges from 0.2°C to 0.4°C per decade, for a total temperature increase to date of 1.5°C ± 0.5°C. EPA notes that flow regulation, land use changes, natural variability, and other factors likely influenced the observed changes, and increased water temperatures may not be ascribed solely to anthropogenic climate change influences.

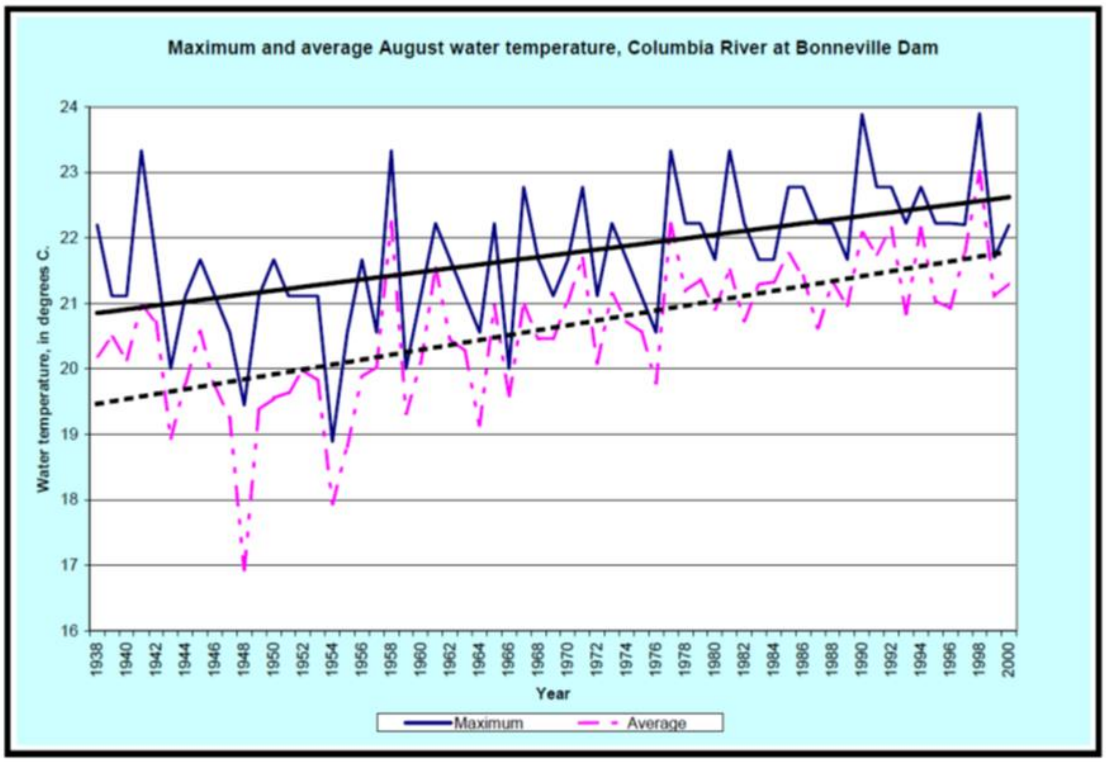


Figure 5-1 Trend in Columbia River August temperatures at Bonneville Dam (National Research Council 2004)

Historic measurement data shown in ***Figure 5-1*** on the Columbia River at Bonneville Dam indicate that the total warming of the river since the late 1930s in August (average) is approximately 2.2°C (dashed line), rising from below 20°C to near 22°C. This increase incorporates all factors in river warming, including dam construction in the middle decades of the century and climate change from 1960 to 2000. It is noted that monitoring data collected at the dams and contained in the DART database prior to 1990 is uncertain due to a lack of data quality procedures. Nevertheless, this is the best available information on historic temperatures, and the increase in August temperatures appears to be generally consistent with current draft estimates of anthropogenic impacts using EPA's RBM10 model (EPA 2018), combined with the climate-related warming since 1960 noted above.

EPA's RBM10 model can predict past temperatures by using historic air temperatures and river flow, and RBM10 model results were considered in the climate trend analysis in Appendix 12.16. ***Figure 5-2*** is a simulation with the existing Columbia and Lower Snake River dams in place (all dams were built prior to 1970 except Lower Granite, which was built in 1975). ***Figure 5-3*** is a simulation without the U.S. Columbia and Lower Snake River dams (the simulation retained Canadian dams on the Columbia River). A comparison of the two figures indicates that August mean Columbia River temperatures at Bonneville Dam would have warmed at a lower rate and to a lesser extent without the dams since 1970. The yellow-dashed line representing the August warming rate in ***Figure 5-2*** shows 0.4°C increase per decade, while the yellow-dashed line in ***Figure 5-3*** shows a 0.26°C increase per decade. For July (red-dashed lines), however, the rate of warming is approximately the same in the two simulations, indicating that the increase in warming since 1970 is primarily attributable to air temperature increases from climate change, and the dams have not exacerbated the warming trend in July.

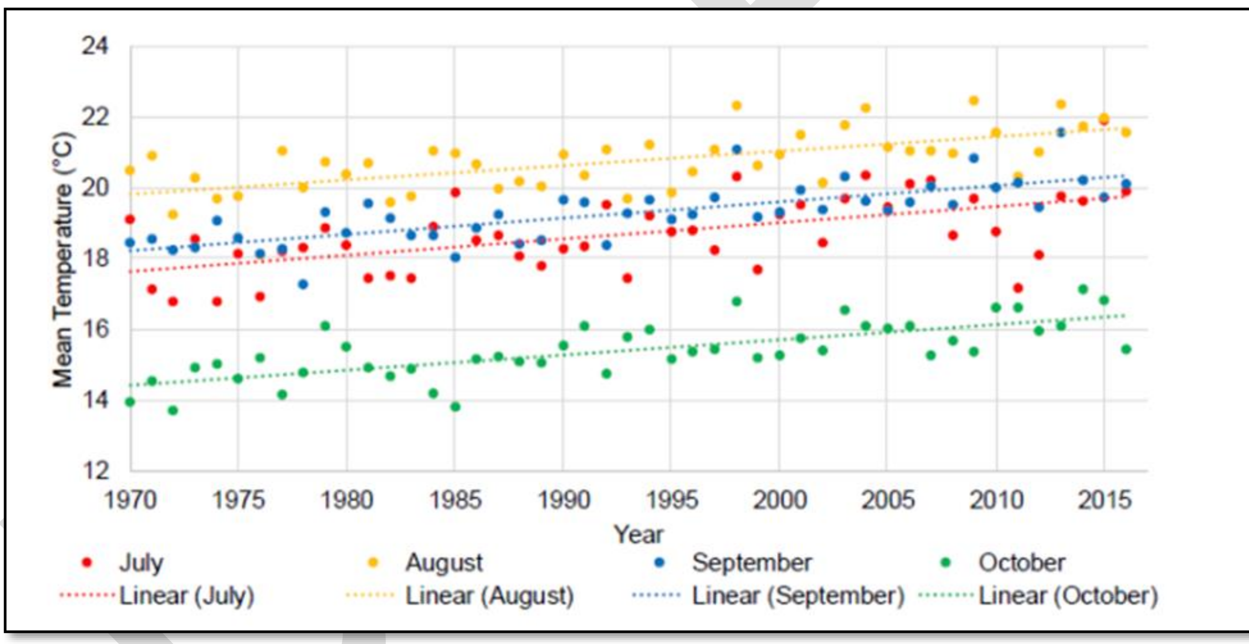


Figure 5-2 Simulated monthly mean temperatures at Bonneville Dam (current) (EPA 2018)

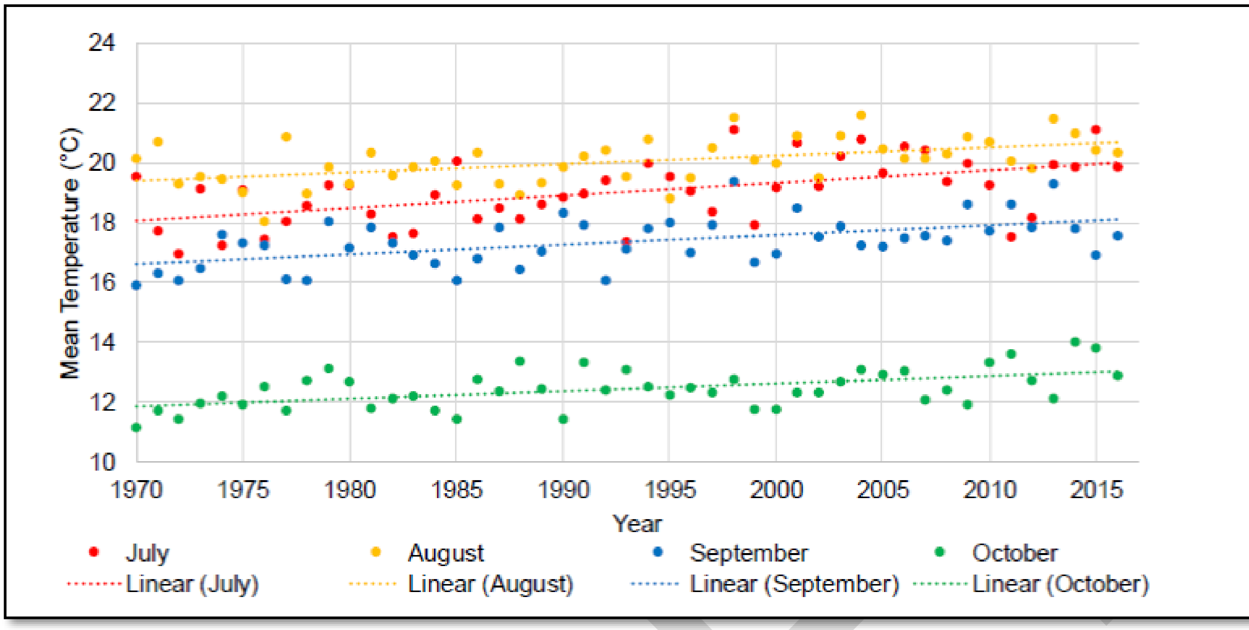


Figure 5-3 Simulated monthly mean temperatures at Bonneville Dam (free flowing) (EPA 2018)

As discussed above in Sections 3.7 and 4.6 above, the increase in summer river temperature has increased the use of cold water refuges (CWR) by steelhead and fall Chinook in the Lower Columbia River, and has contributed to increased mortality of migrating adult sockeye and summer Chinook, and is contributing to earlier sockeye salmon and summer Chinook runs.

5.2 FUTURE TEMPERATURE CONDITIONS OF THE LOWER COLUMBIA RIVER AND ITS TRIBUTARIES

Climate change has already and is projected to continue to influence river temperatures across the Northwest, including the temperatures of the Columbia and Snake Rivers, and will influence multiple aspects of river hydrographs, including timing and magnitude of river flow. As noted above, climate change is estimated to have increased temperatures in the Columbia and Snake River mainstems by 1.5°C ± 0.5°C since 1960 (0.3°C per decade). From this new baseline, the warming trend is expected to continue in the coming decades.

Figure 5-4, ***Figure 5-5***, and ***Figure 5-6*** display Lower Columbia River August mean temperatures under current conditions, 2040, and 2080, respectively, assuming a continuation of the 0.3°C degree per decade warming trend. A continued 0.3°C degree per decade warming trend is very similar to Lower Columbia River model predictions using the AB1 scenario of future greenhouse emissions and global warming (Isaak et al. 2018, Yearsley 2009, Appendix 12.19), which represents a mid-range reduction in annual global greenhouse gas emissions over the 21st century.

As shown in ***Figure 5-5*** and ***Figure 5-6***, August mean temperatures in the Lower Columbia River are projected to increase from near 22°C currently to near 23°C in 2040 and near 24°C in

2080. August mean temperatures in the 23-24°C range would likely result in a significant amount of lethality to migrating adult salmon and steelhead (***Table 4-1***). It is therefore likely that fewer salmon and steelhead will migrate in the Lower Columbia River during mid-July through August in the future under these warming trends, resulting in a change in the timing of salmon and steelhead runs. Adult sockeye salmon and summer Chinook will likely continue to migrate earlier as already observed, with very few migrants in July. Adult fall Chinook are likely to migrate later with minimal migrants in August, and those that do migrate then will likely need to use CWR to have sufficient energy to successfully spawn. Steelhead may use CWR for longer duration to avoid peak temperatures, or they may not be able to use CWR over the mid-summer like they currently do because mainstem temperatures are too warm in late July/early August for steelhead to reach the CWR in the Bonneville reach. If the latter proves true, this may result in a bi-modal migration pattern for steelhead with early summer and late summer runs. However, whether these species can shift their migration timing to adapt to the rate of warming, and whether such shifts can be done successfully without disruption to their full freshwater life cycle, is uncertain (Crozier et al. 2011 and Keefer & Caudill 2017).

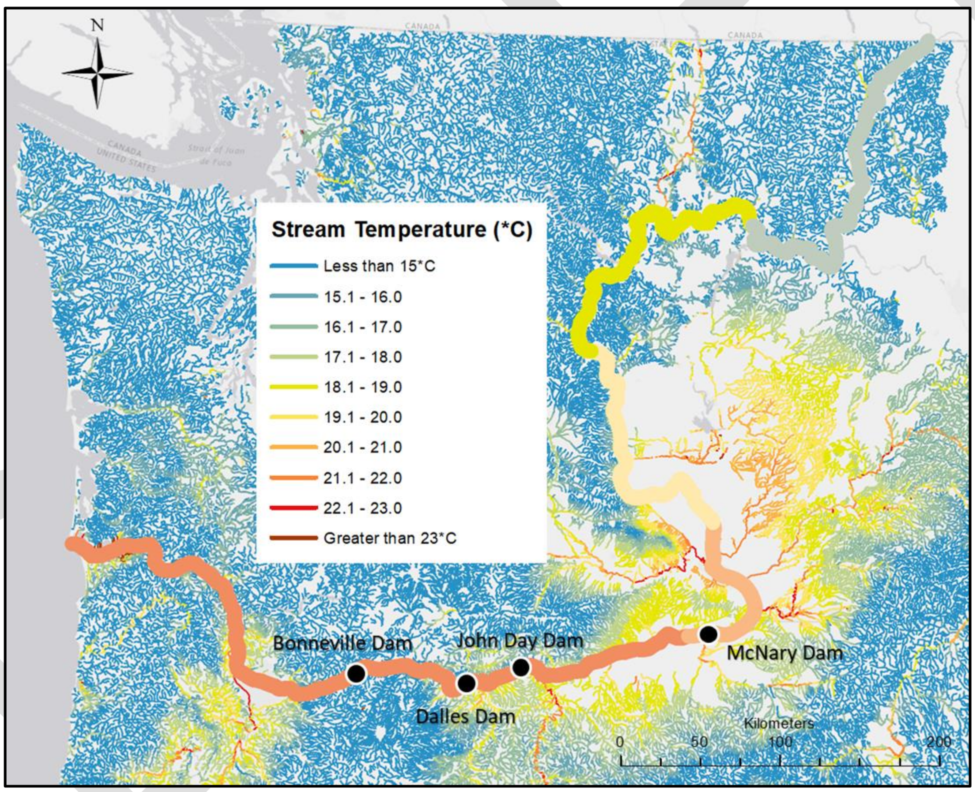


Figure 5-4 Current August mean water temperature in the Columbia River and tributaries (2011-2016) (Appendix 12.14)

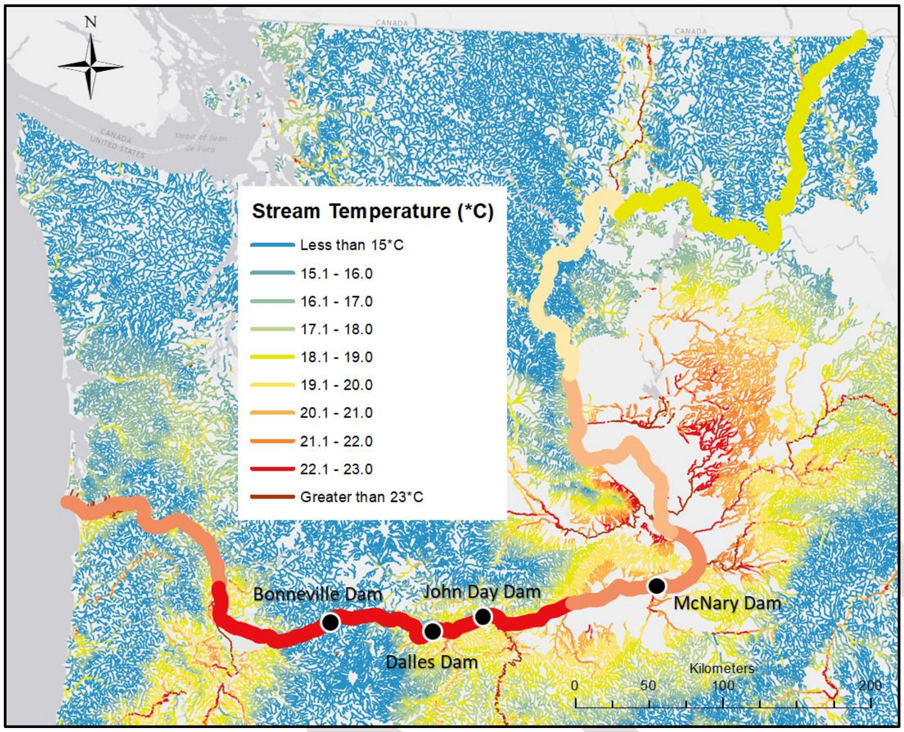


Figure 5-5 Estimated 2040 August mean water temperature in the Columbia River and tributaries (Appendix 12.14)

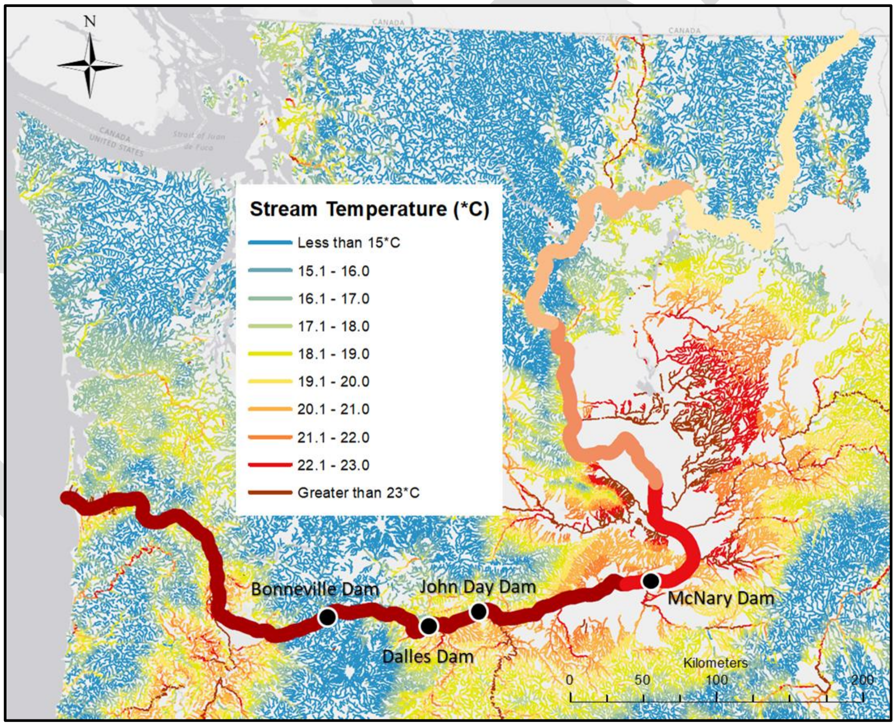


Figure 5-6 Estimated 2080 August mean water temperature in the Columbia River and tributaries (Appendix 12.14)

Temperatures in the tributaries to the Lower Columbia River, including the 23 tributaries that currently provide CWR, are also predicted to increase due to climate change. ***Table 5-1*** displays the predicted increase in August mean temperatures for the 23 CWR tributaries (12 primary CWR highlighted in blue) using the NorWeST SSN model (Appendix 12.17). August mean temperatures for the CWR tributaries are predicted to increase by 1.2–1.5°C by 2040 and by 2.1–2.7°C by 2080 relative to current baseline (1995–2011).

Of significant concern are those primary CWR tributaries that are predicted to have August mean temperatures that exceed 18°C. Tributary temperatures exceeding 18°C, although still serving as CWR if more than 2°C cooler than the Columbia River, are at levels associated with increased risk of disease and energy loss. For instance, by 2040, the Deschutes, Lewis, and Sandy Rivers are predicted to exceed 18°C, temperatures that will diminish their CWR function. By 2080, the Cowlitz, White Salmon, and Klickitat Rivers are predicted to have August mean temperatures exceeding 18°C, diminishing their CWR function.

Table 5-1 Future temperature conditions of the Lower Columbia River tributaries (Appendix 12.17)

Tributary Name	**Current (°C)** (1995-2011)	**2040 (°C)**	**Change between 2040 and current (°C)**	**2080 (°C)**	**Change between 2080 and current (°C)**
Skamokawa Creek	16.2	17.6	1.4	18.6	2.4
Mill Creek	14.5	15.9	1.4	16.8	2.3
Abernethy Creek	15.7	17.1	1.4	18.1	2.4
Germany Creek	15.4	16.8	1.4	17.8	2.4
Cowlitz River	16.0	17.4	1.4	18.4	2.4
Kalama River	16.3	17.7	1.4	18.8	2.5
Lewis River	16.6	18.0	1.4	19.0	2.5
Sandy River	18.8	20.3	1.5	21.4	2.6
Washougal River	19.2	20.7	1.5	21.8	2.7
Bridal Veil Creek	11.7	12.9	1.2	13.8	2.1
Wahkeena Creek	13.6	15.0	1.3	15.9	2.3
Oneonta Creek	13.1	14.4	1.3	15.4	2.2
Tanner Creek	11.7	12.9	1.2	13.8	2.1
Eagle Creek	15.1	16.5	1.4	17.5	2.4
Rock Creek	17.4	18.9	1.5	19.9	2.5
Herman Creek	12.0	13.4	1.4	14.3	2.3
Wind River	14.5	15.9	1.4	16.8	2.4
Little White Salmon River	13.3	14.8	1.4	15.7	2.3
White Salmon River	15.7	17.2	1.5	18.2	2.4
Hood River	15.5	17.0	1.4	17.9	2.4
Klickitat River	16.4	17.8	1.5	18.8	2.4
Deschutes River	19.2	20.7	1.5	21.7	2.5
Umatilla River	20.8	22.4	1.5	23.4	2.6

6 SUFFICIENCY OF COLD WATER REFUGES IN THE LOWER COLUMBIA RIVER

6.1 CWR SUFFICIENCY ASSESSMENT FRAMEWORK

Assessing whether there is a sufficient amount of cold water refuge in the Lower Columbia River to attain the Oregon water quality standard is complex. Oregon's CWR narrative standard stipulates the Lower Columbia River must have CWR that is sufficiently distributed so as to allow salmon and steelhead migration without significant adverse effects from higher water temperatures elsewhere in the water body (i.e., Columbia River). Oregon, however, does not have quantitative metrics to define what is sufficient so this Chapter includes a framework to make this assessment given the current state of information available.

Through the scientific assessment and development of this Plan, EPA identified important context issues for the evaluation of CWR sufficiency. The first issue is the assumption that CWR are beneficial to migrating salmon and steelhead in the Lower Columbia River. There are two exceptions to this assumption in the Lower Columbia River. The first exception is fish mortality from fishing in CWR. As presented in Section 4.3, fish that enter into CWR have a lower adult migration survival rate through the Lower Columbia River compared to fish that do not use CWR. This appears to be explained by fish harvest in CWR and mortality of caught and released fish. However, the role of water quality standards under the Clean Water Act (CWA) is to ensure the water is of sufficient quality (in this case, water temperature) to protect designated uses of the water body (in this case, salmon and steelhead). Therefore, EPA did not consider fishing mortality in the assessment of CWR sufficiency, recognizing that the amount of fish mortality in CWR can change through fish management decisions. Thus, EPA evaluated the sufficiency of CWR in the Lower Columbia River as if there was no fishing to focus our assessment on water quality conditions to support migrating salmon and steelhead.

The second exception to the assumption that CWR are beneficial to migrating salmon and steelhead is that using CWR may induce fish to enter CWR and ultimately cause more harm due to the delay in their migration. As discussed in this Plan, sockeye salmon and summer Chinook migrate through the Lower Columbia River prior to the onset of the warmest summer temperatures, and extended CWR use would likely be harmful due to exposure to warmer conditions during their continued migration. With these two exceptions explained, the evidence presented in this Plan suggests that CWR use appears to be physiologically beneficial for those species that use CWR the most, which are summer steelhead and fall Chinook.

The second context issue is the temperature of the Columbia River itself. As described in this Plan, the degree to which salmon and steelhead use CWR depends on the Columbia River mainstem temperature. The warmer the river, the more fish use CWR. Thus, assessing CWR sufficiency can be viewed as a function of the Columbia River temperature. However, although CWR can help mitigate adverse effects to migrating salmon and steelhead when Columbia River temperatures exceed 20°C, the CWR narrative standard should not be interpreted to "allow for" or to "fully compensate for" Columbia River water temperatures higher than the 20°C numeric criterion.

EPA assessed the CWR sufficiency element of the Oregon CWR narrative criteria based on current Columbia River conditions because of available water quality data, and because water quality standard assessments are generally based on current conditions. However, to address the dynamic of different temperatures in the Lower Columbia River, EPA evaluated sufficiency at three different temperature regimes: August mean temperature of 20°C, which reflects past historic conditions; 21.5°C, which reflects current conditions; and 22.5°C, which reflects a predicted 2040s condition. This analytical framework to address sufficiency is helpful to understand the use of CWR in the past, present, and future. Some of the recommendations in the plan consider predicted future temperature conditions in the Lower Columbia River and the CWR tributaries as practical considerations to improve water quality for migrating salmon and steelhead.

To evaluate sufficiency of CWR at different Lower Columbia River temperatures, EPA considered several factors based on information presented in previous chapters, as well as in the HexSim model discussion below: (1) the extent of CWR use in terms of number of salmon and steelhead in CWR and the proportion of the run using the CWR; (2) a qualitative assessment of the potential for the current volume of CWR to have capacity limitations; (3) the distribution of CWR in the Lower Columbia River; (4) observed and modelled indicators of fish health and risk, including mortality rates, energy loss, and cumulative exposure to stressful temperatures for migrating salmon and steelhead in the Lower Columbia River; and (5) the overall importance of adult migration risk factors in the recovery of salmon and steelhead from review of ESA recovery plans and NOAA's Columbia River Systems Operations Biological Opinion.

6.2 HEXSIM MODEL

To aid in examining sufficiency of CWR in the Lower Columbia River, EPA developed a fish behavior simulation model using the HexSim modeling platform (Schumaker and Brookes, 2018) that simulates behavior, movement, and tracks thermal exposure of individual fish migrating through the Lower Columbia River. The model description and the initial application of the model through the Bonneville reach of the Columbia River between Bonneville Dam and The Dalles Dam is summarized in Snyder et al. 2019. The model has been expanded to include the 178-mile portion of the Columbia River from Bonneville Dam to the Snake River confluence.

The HexSim model provides the opportunity to simulate different scenarios and evaluate how they affect CWR use and important indicators related to fish health. For the initial model runs for this draft Plan, EPA selected the following scenarios: (1) existing CWR; and (2) no CWR. Both scenarios were run under different Columbia River temperatures representing past, current, and predicted future conditions. These model scenarios help examine how CWR use affects fish health indicators at different Columbia River temperatures. Health indicators assessed include cumulative energy expenditure, cumulative degree days above warm temperature thresholds (e.g., 21°C and 22°C), and predicted acute mortality between Bonneville Dam and the confluence with the Snake River. EPA evaluated these scenarios and resultant indicators for two populations of summer steelhead, Grande Ronde summer steelhead and Tucannon summer steelhead; and two populations of fall Chinook salmon, Snake River fall Chinook and Hanford reach fall Chinook. The results of these preliminary model runs are presented in Appendix 12.21.

The following is a summary of the preliminary HexSim model assessment. The summary below highlights model results for Grand Ronde summer steelhead because that population represents a steelhead population that use CWR extensively, as shown in Section 3.9.

Cumulative Number of Hours in CWR as a Function of Columbia River Temperature

The number of hours individuals spend in CWR increases with increased Columbia River temperatures for all four populations evaluated, which is consistent with the CWR use estimates in Chapter 3. For Grande Ronde steelhead, the number of hours in CWR is modeled to be 0.7 million (past/historic temperatures), 2.3 million (current temperatures), and 2.9 million (predicted 2040 temperatures) (Appendix 12.21).

Energy Loss under Different Scenarios

The energy loss (fat loss) within the model reach (Bonneville Dam to Snake River confluence) increased for all four populations with increased Columbia River temperatures. ***Figure 6-1*** shows the summary of energy loss for Grande Ronde summer steelhead for the different scenarios. If too much energy is lost during migration and pre-spawning, a fish may not have enough energy to complete spawning as discussed in Section 4.5. Because use of CWR increases the amount of time in the model reach, CWR use somewhat increases the population median amount of energy loss in the model reach relative to no CWR use as shown in ***Figure 6-1***. However, to evaluate the implications of energy use on spawning success, energy loss needs to be evaluated within the context of the entire migratory journey, including holding and spawning. For example, Grande Ronde summer steelhead migrate another 170 miles upstream in the Snake River before traveling up the Grande Ronde River to their spawning grounds. Under scenarios of no CWR use, there is a much earlier average arrival at the end of the modeled reach (Snake River confluence) (***Figure 6-2***), when Snake River temperatures are warmer. The use of CWRs extends the range of arrival dates at the Snake River confluence, which may decrease energy loss for those late arriving individuals who will then migrate through the Snake River when it is cooler. Therefore, while the entire population does not see an energy benefit in the model reach of the migration corridor, CWRs potentially increase the diversity of energy conserving migration strategies.

In summary, it is necessary to model the full migration to the spawning grounds to fully assess energy loss and the potential for pre-spawning mortality, as was done in the Plumb (2018) and Conner et al. (2018) papers, which concluded CWR in the Lower Columbia River were beneficial to reduce pre-spawning mortality for early migrating Snake River fall Chinook (Section 4.5). These papers indicate that most of the energy loss for Snake River fall Chinook occurs upstream of the Lower Columbia River. Thus, the river temperature during the latter part of the fall Chinook migration, when the fish are preparing to spawn, is an important factor in spawning success, and CWR in the Lower Columbia River can serve to allow the fish to arrive at the spawning grounds when river temperatures are cooler.

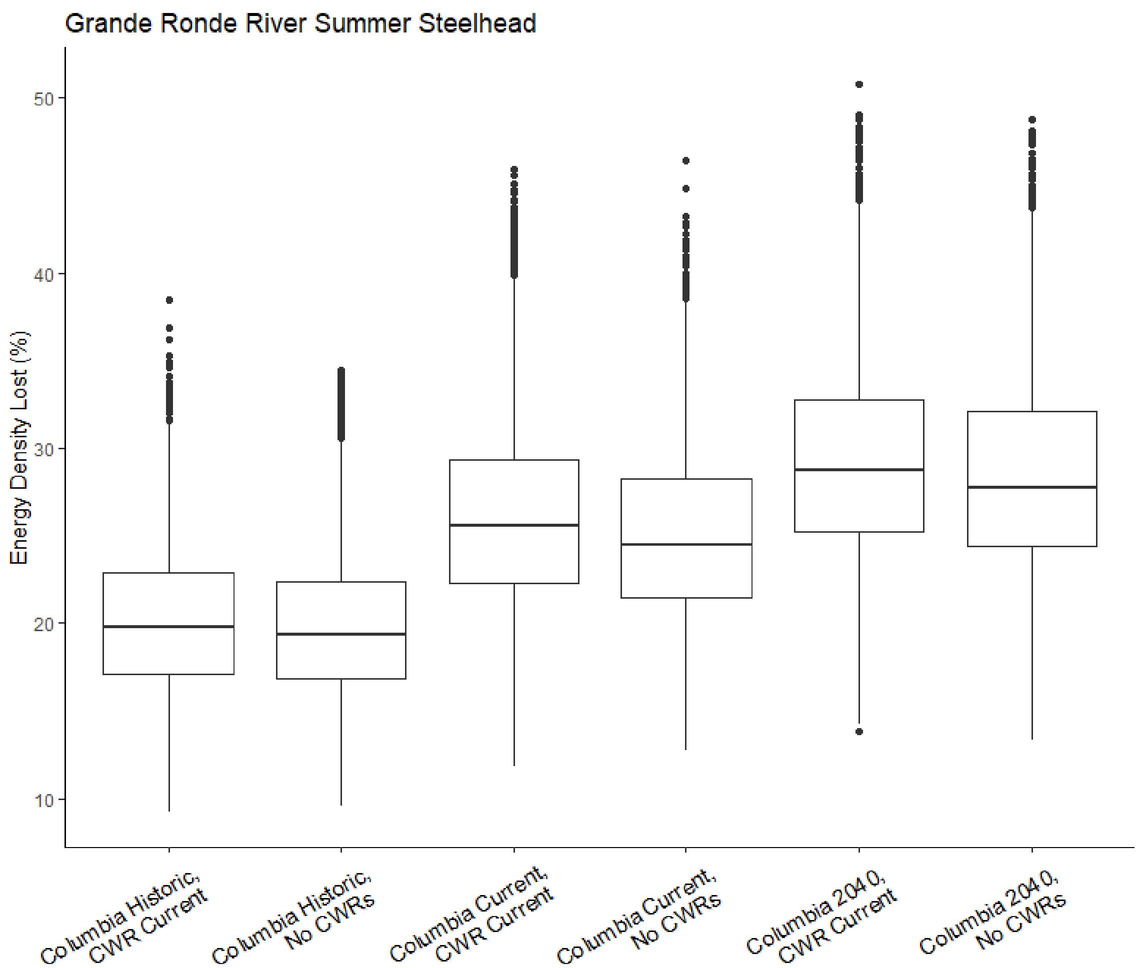


Figure 6-1 Simulated energy loss for Grande Ronde summer steelhead from Bonneville Dam to the Snake River under various scenarios (Appendix 12.21)

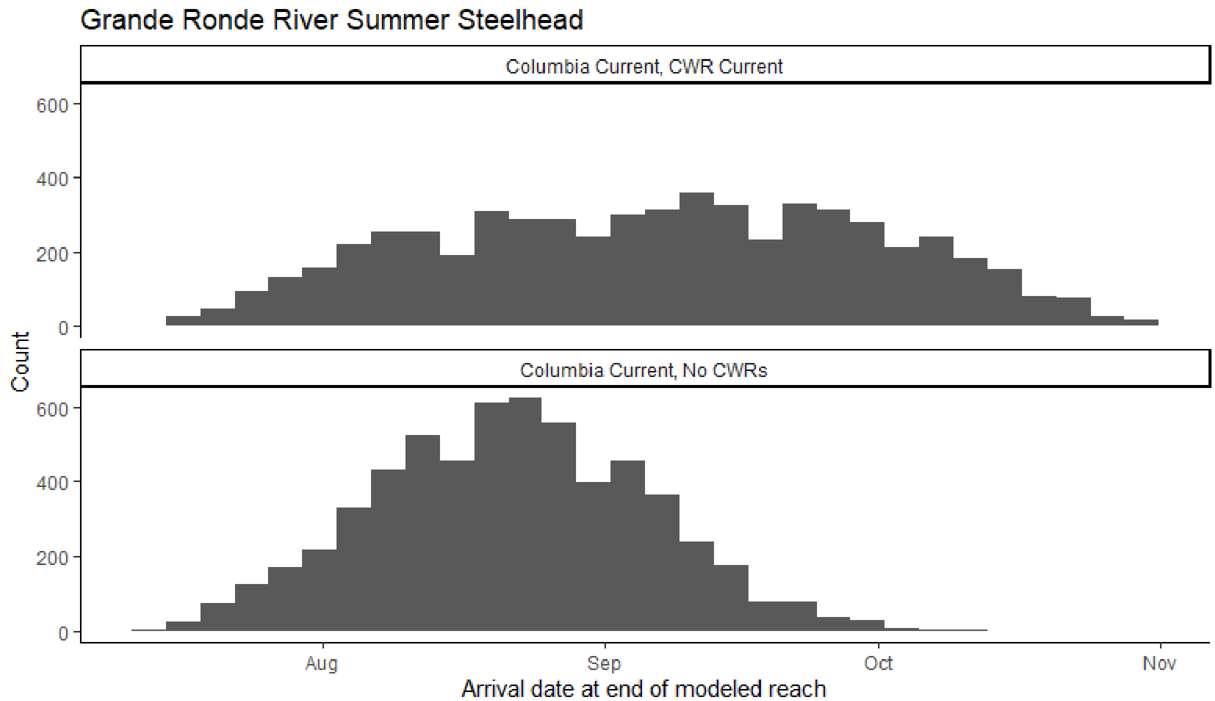


Figure 6-2 Simulated arrival date at the Snake River for Grande Ronde summer steelhead with and without CWR use (Appendix 12.21)

Acute Mortality

The model runs for current and past Columbia River temperature with and without CWR did not show any acute mortality for the four populations in the model reach. This was not unexpected because acute temperature stress mortality in the model is based on 24-hour exposure, which begins to occur near 24°C (less than 1% chance) and climbs to 10% chance at 27°C. Columbia River temperatures currently do not reach these levels.

Cumulative Degree Days under Different Scenarios

The model runs show large differences in cumulative degree days above warm temperature thresholds of 21°C and 22°C with and without CWR for Grande Ronde steelhead. As shown in ***Figure 6-3***, under current Columbia River temperatures the cumulative degree days above 21°C is much higher if there were no CWR compared to the current amount of CWR. The average number of cumulative degree days above 21°C is 139 for a Grande Ronde summer steelhead using CWR. If no CWR were available, it would be 272.

Figure 6-4 shows the cumulative degree days above 22°C for Grande Ronde steelhead. Under current Columbia River temperatures, the 10-year mean of daily average temperatures (reflected in ***Figure 6-4***) rarely exceeds 22°C in the Columbia River so cumulative degree days above 22°C are near zero with and without CWR. However, under predicted 2040 conditions, the cumulative degree days above 22°C for a typical Grande Ronde steelhead will be higher (286) if no CWR were available compared to the current amount of CWR (118). It is also notable that for current warm years (e.g. 2017 and other recent warm years when Columbia River temperatures were warmer than the 10-year average with numerous days exceeding 22°C), CWR use reduced the cumulative exposure for steelhead above 22°C, similar to what is displayed in ***Figure 6-4*** for 2040 average temperatures (Appendix 12.21).

The difference in cumulative degree days above the 21°C and 22°C thresholds illustrates the benefits of CWR use for migrating steelhead by avoiding peak warm temperatures and is consistent with the information and discussion presented in Chapter 3. Prolonged exposure to temperatures greater than these thresholds is stressful for migrating salmon and steelhead and increases disease risk associated with mortality as discussed in Chapter 4.

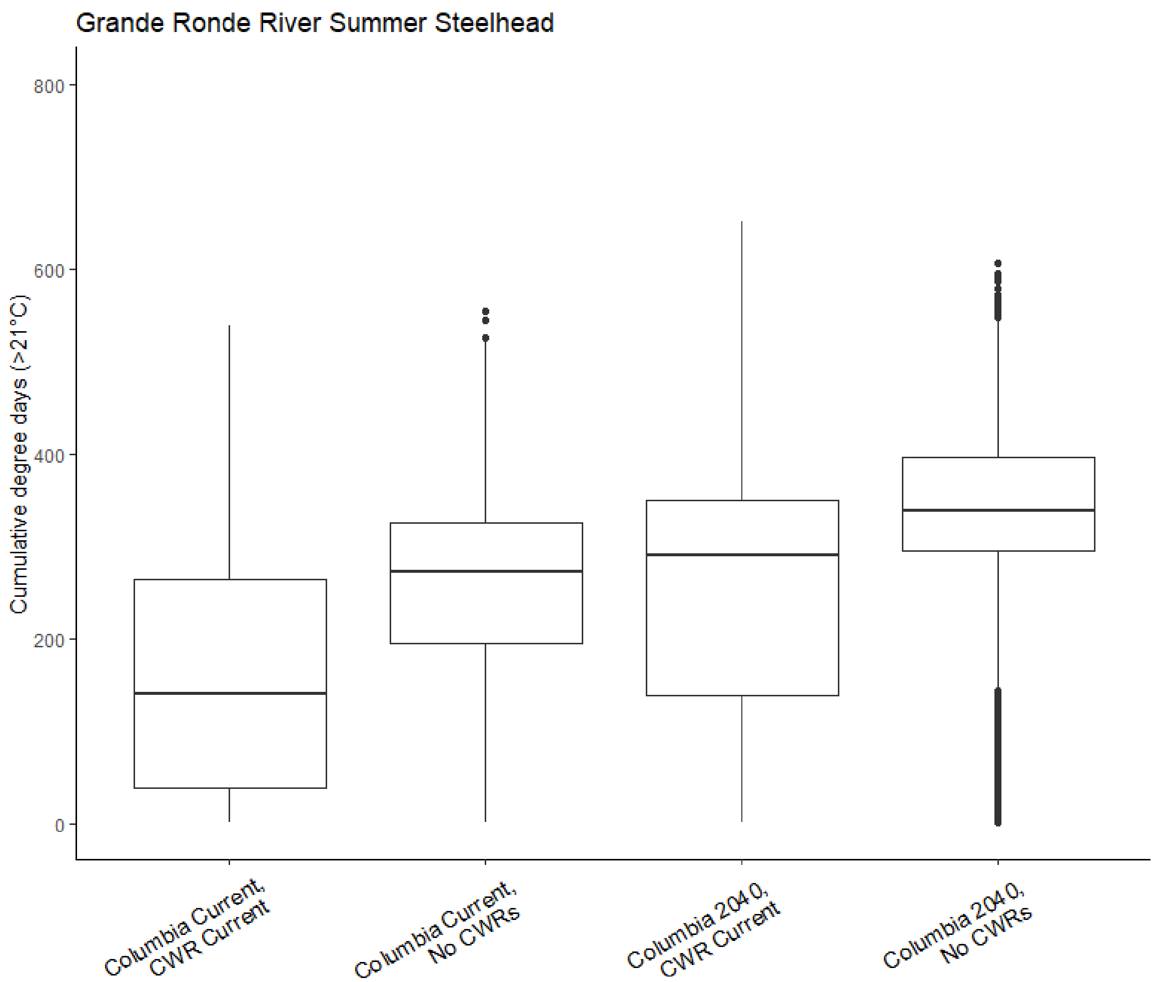


Figure 6-3 Simulated cumulative degree days above 21°C for Grande Ronde summer steelhead between Bonneville Dam and the Snake River under different scenarios (Appendix 12.21)

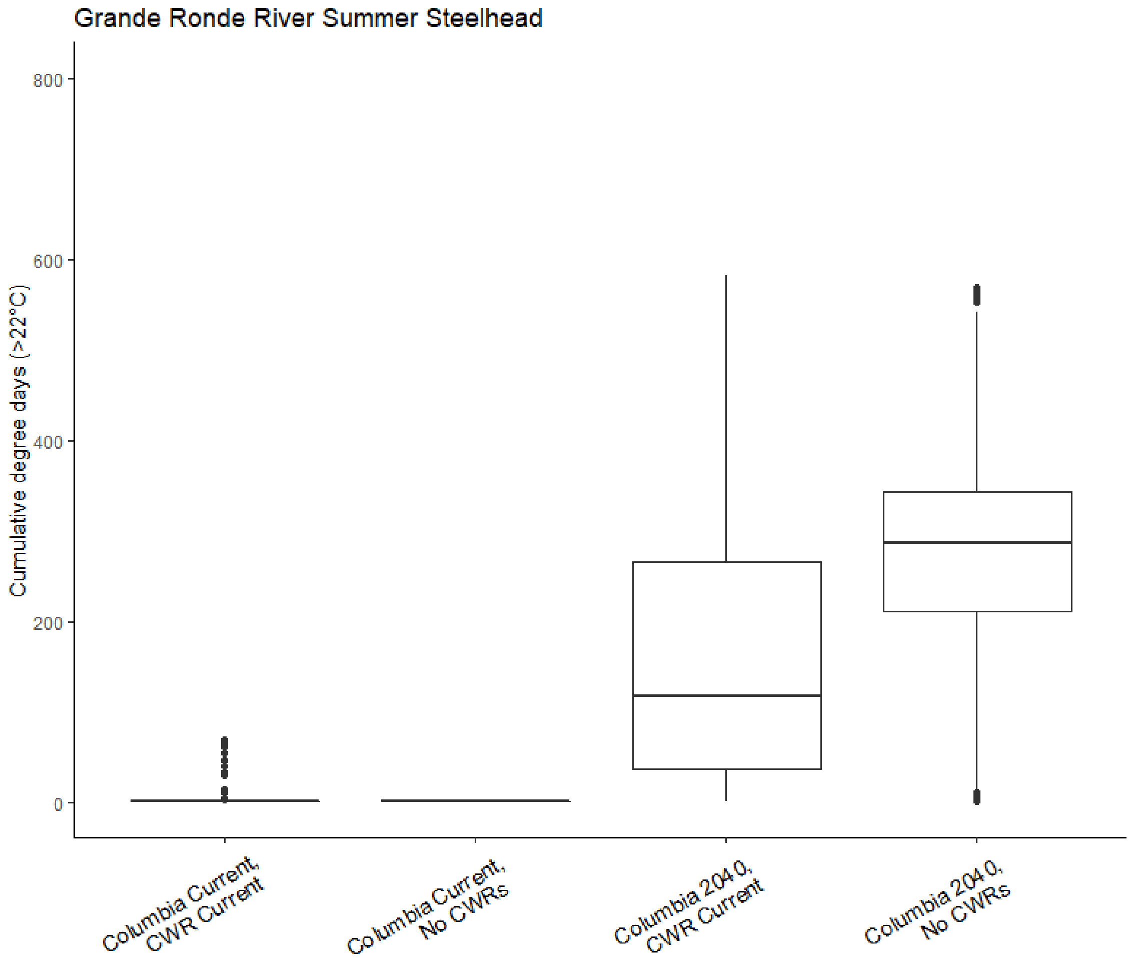


Figure 6-4 Simulated cumulative degree days above 22°C for Grande Ronde summer steelhead between Bonneville Dam and the Snake River under different scenarios (Appendix 12.21)

6.3 ASSESSMENT ON CWR SUFFICIENCY

As noted above, EPA assessed CWR sufficiency to support salmon and steelhead under current (21.5°C) Lower Columbia River August mean temperatures, considering the factors listed in Section 6.1. For context, EPA also evaluated CWR sufficiency under past (20°C) and future (22.5°C) conditions.

Current Conditions: Fish Use and CWR Capacity

When the Lower Columbia River is 21.5°C (August mean), which reflects current conditions, EPA's assessment is that the current amount of CWR appears to be sufficient to support migrating salmon and steelhead based on the factors discussed below. There is, however, a fair degree of uncertainty to this assessment. As shown in Chapters 2 and 3, current Lower Columbia River temperatures typically exceed 20°C for two months and exceed 21°C for one month, and use of available CWR by steelhead and fall Chinook is well documented and extensive. Based on information in Chapters 3, 4, and HexSim model results, current steelhead and fall Chinook use of CWR appears to provide some individuals physiological and energetic benefits by allowing them to avoid warm mid-summer Columbia River temperatures and continue migrating upstream when temperatures have cooled. The CWR provide for a diversity of successful migration strategies. From the density estimates in Chapter 3 and HexSim modelling, it does not appear the capacity in CWR is exceeded, except for Eagle Creek and Rock Creek. The HexSim model showed these small CWR reaching capacity (Snyder et al. 2019). EPA reviewed literature on the density of adult salmon fish in aquaculture facilities to define a maximum fish density of 1 fish per cubic meter, but it is uncertain whether this is representative of maximum density in CWR (Berejikian et al. 2001). Therefore, findings on the density capacity of CWR are uncertain.

Current Conditions: CWR Distribution

Regarding the distribution of CWR in the Lower Columbia River, migrating salmon and steelhead have several CWR opportunities below Bonneville Dam and extensive CWR opportunities in the Bonneville Dam reservoir reach and the Deschutes River above The Dalles Dam (see ***Figure 2-8***). The cluster of CWR in the Bonneville Dam reservoir reach and the Deschutes River is approximately mid-way from the ocean to the confluence of the Snake River. It takes approximately one week for salmon and steelhead to travel from the ocean to this cluster of CWR and another week to pass the McNary Dam and get to the Snake River confluence area. Thus, the CWR distribution is advantageous in that the CWR provide the opportunity to escape the warm Columbia River mid-way through their upstream migration of the Lower Columbia River and avoid approximately two weeks of continuous exposure to warm temperatures over this 325-mile reach.

However, the lack of CWR in the nearly 100 miles between the Deschutes River and McNary Dam, including the John Day reservoir which has the highest temperatures in the Lower Columbia River, is of concern. This nearly 100-mile reach poses the greatest risk from warm temperatures for migrating salmon and steelhead. Thus, it is difficult to conclude that CWR distribution is sufficient based solely on locations. In addition, there is very little opportunity to restore CWR in this reach, and even under natural conditions there were likely only a few small tributaries (e.g. Willow Creek, Rock Creek) and the Umatilla River that provided CWR.

Current Conditions: Adult Survival

The strongest line of evidence that the current amount of CWR is sufficient under current Columbia temperatures is the adult survival rates from Bonneville Dam to McNary Dam. As discussed in Section 4.4, the adult survival rate after accounting for harvest and straying for Snake River steelhead and fall Chinook is over 90%. ***Table 2-1*** shows the most recent estimates of adult survival after accounting for harvest and straying for Snake River species from Bonneville Dam to McNary Dam from 2012-2016 (NOAA 2017b). Snake River fall Chinook adult survival is near 96% and Snake River steelhead is 93%. While NOAA recognizes that warm Lower Columbia River temperatures are a concern and a limiting factor in the recovery of ESA-listed species that migrate up the Lower Columbia River, NOAA does not view adult migration conditions in this river segment as “substantially impaired” for upper Columbia and

Snake River steelhead and Snake River fall Chinook based on adult survival statistics (NOAA 2019).

Table 6-1 Adult salmon and steelhead survival estimates after correction for harvest and straying based on PIT-tag conversion rate analysis from Bonneville (BON) to McNary (MCN) dams, McNary to Lower Granite (LGR) dams, and Bonneville to Lower Granite dams (NOAA 2017b).

Species	Years	BON to MCN	MCN to LGR	BON to LGR
SR Fall Chinook	2012-2016 Avg	95.8%	94.9%	91.0%
SR Spr/Sum Chinook	2012-2016 Avg	93.1%	94.0%	87.3%
SR Sockeye	2012-2016 Avg	59.9%	74.2%	49.7%
SR Steelhead	2012-2016 Avg	93.2%	94.3%	87.9%

The current amount of CWR may be helping to maintain the survival rates (after adjusting for harvest and straying) above 90% shown in ***Table 6-1*** by minimizing salmon and steelhead exposure to peak summer temperatures in the Lower Columbia River. As illustrated in ***Figure 6-3*** for Grand Ronde steelhead, CWR use relative to no CWR use reduces the cumulative exposure to temperatures above 21°C, which is associated with increased stress and disease mortality. Moreover, CWR use in the Lower Columbia River also reduces cumulative exposure to warm temperatures for fish migrating up the Snake River due to migrating later in the summer/fall, which likely aids in the survival rates up the Snake River to Lower Granite Dam (LGR). Notably, Snake River sockeye, which do not use CWR due to their early summer run timing, have a much lower adult survival rate due to mortality from warm Columbia River temperatures as discussed in Chapter 4.

Snake River summer steelhead and Snake River fall Chinook adult survival rates (NOAA 2017b) from Bonneville Dam to McNary are generally representative of survival rates of other steelhead species (upper Columbia River and middle Columbia River) and other fall Chinook species (Hanford reach) that use CWR. As presented in Section 3.9, upper Columbia River steelhead migrate earlier in the year compared to Snake River steelhead and therefore have less overall exposure to warm Lower Columbia River temperatures and use CWR less. Likewise, most Hanford reach fall Chinook migrate later than Snake River fall Chinook and therefore have less overall exposure to warm Lower Columbia River temperatures and use CWR less.

In summary, primarily because there does not appear to be capacity limitations on the use of CWR in the Lower Columbia River, and adult steelhead and fall Chinook migration survival rates exceed 90% in this reach, EPA's assessment is that the current amount of CWR is sufficient under current Columbia River temperatures.

Past Conditions

When the Lower Columbia River is 20°C (August mean), which represents historic Columbia River temperatures, EPA's assessment is that the current amount of CWR appears to be sufficient to support migrating salmon and steelhead. Under the scenario of 20°C, CWR use is modest by steelhead and very limited for fall Chinook, as first described in Chapter 3. The level of CWR use when August mean temperature is 20°C is far less than what is observed under current conditions. Because the current CWR volume appears to be sufficient under current Columbia River temperatures, as discussed above, the current CWR volume would also be sufficient when the Columbia River is cooler. Although an August mean temperature of 20°C during migration is above optimal and present risks in terms of elevated disease occurrence and sub-lethal effects, observed mortality to migrating adults is very low under these conditions.

Future Conditions

When the Lower Columbia River is 22.5°C (August mean), which reflects predicted future (2040) conditions, EPA's assessment is that there is significant risk that the current amount of CWR will not be sufficient to minimize the risk to migrating salmon and steelhead. As presented in this Plan, a warmer Lower Columbia River at these temperatures (22.5°C August mean with daily average temperatures frequently reaching 23-24°C) will significantly increase the stress, energy loss, and mortality risk to salmon and steelhead migrating in the Lower Columbia River in the summer. Under these temperatures, the extent of CWR use, as discussed in Chapter 3 and presented in HexSim model results, is expected to be higher. Steelhead may be less apt to leave the CWR at these peak summer temperatures. Further, these temperatures will trigger fall Chinook to use CWR at a higher rate. As a result, the density of fish in CWR will be higher, calling into question the capacity of the currently available CWR. Additionally, the CWR tributaries are predicted to warm. This is of particular concern for marginal CWR (***Table 7-1***). For example, the Deschutes River, which although cooler than the Columbia River, currently has an August mean temperature of 19°C, which is above optimal for migrating salmon. These factors suggest there is significant risk that the Lower Columbia River adult migration survival rates for steelhead and fall Chinook will decrease in the future.

Conclusion

EPA's assessment is that the spatial and temporal extent of existing CWR appears to be sufficient under current and 20°C Columbia River temperatures but may not be in the future. Therefore, maintaining the current temperatures, flows, and volumes of the 12 primary CWR in the Lower Columbia River is important to limit significant adverse effects to migrating adult salmon and steelhead from higher water temperatures elsewhere in the water body. Further, additional CWR in the Lower Columbia River may be needed due to the predicted continued gradual warming of the Columbia River. The 11 non-primary CWR tributaries and other potential tributaries may provide additional CWR through restoration and enhancement.

7 ACTIONS TO PROTECT & RESTORE COLD WATER REFUGES

As summarized in Chapter 6, EPA assessment is that to provide sufficient cold water refuges (CWR) in the Lower Columbia River to support migrating adult salmon and steelhead, it will be necessary to maintain the existing amount of cold water that is provided by the 12 primary CWR tributaries. In addition to these 12 primary tributaries, EPA has highlighted two tributaries that could be restored (the Umatilla River and Fifteenmile Creek) to provide additional CWR. EPA prioritized the Umatilla River as an important river to restore due to: 1) its relatively substantial flow compared to the other non-primary CWR, 2) its location as the only significant opportunity for increased CWR in the warm 93-mile reach between the Deschutes River CWR and McNary Dam, and 3) temperature total maximum daily loads (TMDL) completed in the Umatilla Basin indicating the potential for decreased summer temperatures in the river (Appendix 12.20). EPA included Fifteenmile Creek to highlight as a tributary with potential to be restored into a quality CWR based on the temperature TMDL suggesting substantial cooling potential and the fact that Fifteenmile Creek has been prioritized for restoration for ESA-listed steelhead recovery. The other 10 non-primary CWR tributaries identified in Chapter 2 may be able to increase the amount of CWR near their confluence areas, if restored. Due to time limitations, EPA did not develop snapshots for those tributaries (Appendix 12.20).

*A temperature **TMDL** is a waterbody plan that sets the maximum amount of heat allowed to enter a waterbody so that the waterbody will meet temperature water quality standards.*

This chapter summarizes actions to protect the 12 primary CWR tributaries to: 1) avoid human actions that could increase temperatures of the tributary, and 2) restore the tributary to cool temperatures to potentially partially or fully counteract predicted warming from climate change (Appendix 12.15). In addition, this chapter summarizes actions to restore the Umatilla River and Fifteenmile Creek watersheds to provide additional CWR. These 14 tributaries are illustrated in ***Figure 7-1***.

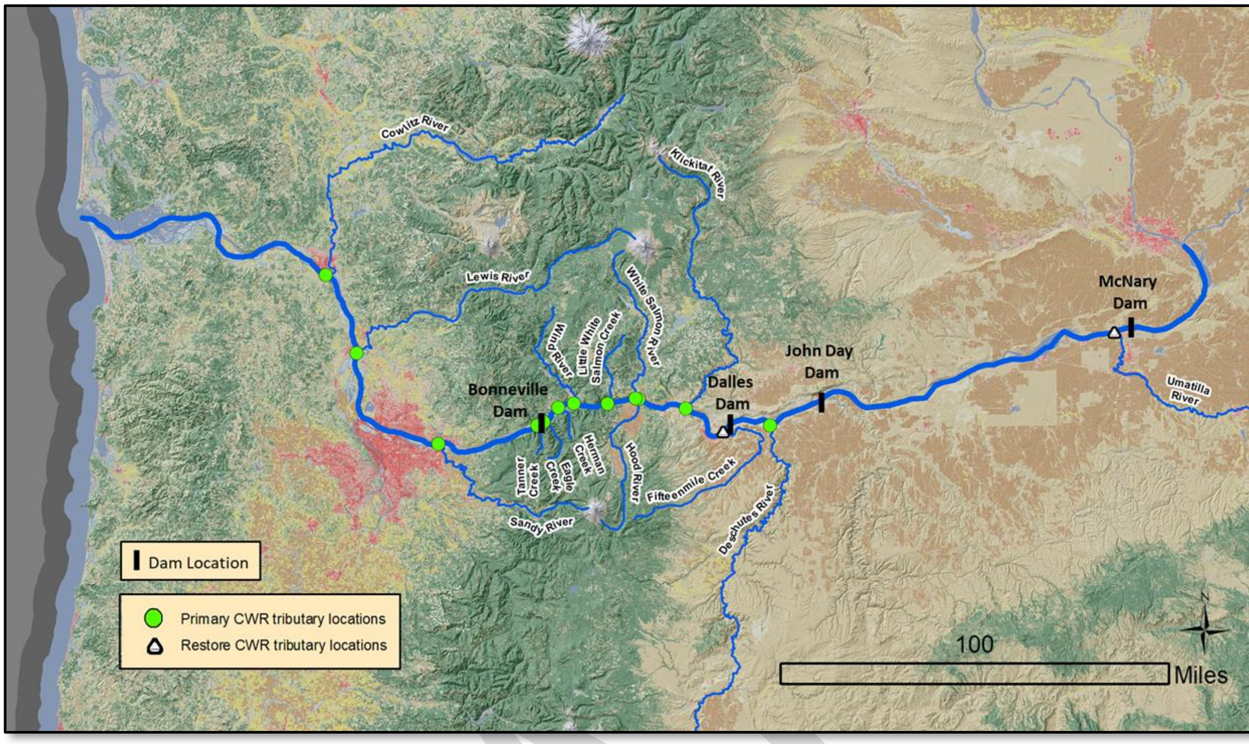


Figure 7-1 12 primary and 2 "restore" cold water refuge tributary locations

7.1 COLD WATER REFUGE WATERSHED SNAPSHOTS

EPA developed "cold water refuge watershed snapshots" of the 12 "primary" CWR tributaries and the 2 "restore" CWR tributaries to provide more detailed information about the CWR and their respective watersheds. The snapshots describe the quality and characteristics of each refuge, background on the watershed, features of the watershed that can affect CWR quality, and actions in the watershed that can protect and restore the CWR.

One focus of the snapshots is to identify watershed features that help to maintain CWR quality. These are used as the basis for actions to protect those watershed features. A second focus is to identify features that degrade CWR quality. These are used as a basis for restoration actions to reduce temperatures and potentially offset future warming from climate change. These protection and restoration actions are regulatory – related to management actions already established – and voluntary in nature. Whenever possible, an effort is made to identify agencies and organizations that have jurisdictional authority over the actions.

The actions are also intended for local stakeholders and regional planning groups to use in focusing their work and leveraging resources for projects that protect and restore CWR. In addition to enhancing CWR quality, many restoration actions are the actions identified for salmon recovery and watershed restoration to benefit species within the watersheds. To this end, the snapshots emphasize ongoing work in the watersheds that provide multiple local benefits in addition to enhancing CWR and put a spotlight on the important regional benefits provided by these restoration actions.

To develop these snapshots, EPA relied on work described in the previous chapters regarding CWR plume volume, upstream extent of fish use, and documented fish use by migrating salmonids. EPA also developed maps for the land cover and land ownership in each CWR tributary and conducted other analyses for riparian cover and water allocation. For background on different activities in each watershed, EPA conducted a literature search relying heavily on sub-basin plans, regional salmon recovery plans and local watershed priority plans. See Appendix 12.20. Chapter 11 includes a bibliography of the sources for each snapshot.

EPA shared drafts of these documents with interested parties in the basin including Tribal Governments, Lower Columbia Estuary Partnership, counties, Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), Washington Department of Ecology, Oregon Department of Environmental Quality (ODEQ), U.S. Forest Service (USFS), watershed councils, and other groups who provided feedback. The snapshots are relatively concise, providing a brief overview of the watersheds, distilling meaningful information for stakeholders, and calling for specific restoration actions.

More detail on the development of the snapshots is included in Appendix 12.20.

7.2 CHARACTERISTICS OF PRIMARY COLD WATER REFUGE TRIBUTARIES

While the 12 primary CWR are distinct tributaries, some share similar characteristics that help to create and maintain cold temperatures during the summer. These similar watershed characteristics mean some of the actions needed to protect and restore these CWR are similar. Other CWR have distinct characteristics - geology, geography, and land use - that make them more unique in the study area. The following section describes the significance of the tributaries' geographic locations, land use, and geology which affects the actions to be taken to protect and enhance their CWR quality.

Figure 7-1 shows that 11 of the 12 primary CWR tributaries originate in forested areas from the Cascade Mountain Range in Washington and Oregon. Many of these areas have similar geologic and geographic features: tributaries that originate in high elevation mountains with snowpack, have large percentages of federally-owned forestlands, and experience cool air temperatures associated with the Cascade Range. The Deschutes River and Klickitat River flow through a warmer climate east of the Cascades and are heavily influenced by groundwater, which helps maintain cool river temperatures. The non-primary Umatilla River also flows through a warmer climate east of the Cascade Range.

The Cowlitz River and Lewis River share similar features. They are the two most downstream CWR in the Columbia River, whose headwaters are in the Cascade Mountain range in Washington. There is development in each of these basins, particularly in the lower reaches of the Cowlitz River. Both rivers have several dams for hydropower and flood prevention which, through sediment containment in reservoirs and alteration to the flow regime, reduce the movement of sediment towards the mouth.

Tanner Creek, Eagle Creek, Wind River, Herman Creek, Little White Salmon River, and the White Salmon River are centrally located in the Cascades. These tributaries have generally cooler air temperatures in the summer and over 80% of their watersheds in forested areas – the highest percentages of forested land and/or federally managed forest land relative to other CWR tributaries. Other tributaries near the mouth of the Columbia River have higher levels of urban development.

The Klickitat River and Deschutes River are located east of the Cascade Mountain range, where the climate is significantly drier and warmer and the percentage of forested land drops significantly. However, both tributaries have volcanic geology which creates opportunity for groundwater infiltration, important for providing a reliably steady source of cold water in the summer which enhances CWR quality.

Many tributaries share a common feature to some extent: sedimentation at the mouth. This is likely due to a combination of factors in the tributaries themselves and in the Columbia River. In the tributaries, natural erosion from past volcanic activity and natural landscape processes coupled with human development may lead to increased sediment entering the Columbia River. In the Columbia River, the dams slow down the river flow, reducing the river's ability to flush sediment and prevent build-up at the mouth of tributaries. Sediment build-up occurs on shallow tributary mouths which may make physical access for salmon difficult and, combined with Columbia River mainstem river water, leads to warmer surface temperatures. Both Herman Creek and the Little White Salmon River drain into artificial cove areas created by infilling (Herman Cove) and by a highway (Drano Lake). These embayments have pooled inflowing cool tributary flows creating coves that provide CWR. Both have sediment deposits that may be reducing CWR volume over time. Herman Cove has been dredged in the past to allow boat access into the cove.

Overall, all the CWR tributaries have cold temperatures in the summer primarily because of snowpack from forested and mountainous areas that either supply cold water or create cold groundwater. The presence of large pools at the mouth is a particularly important feature that attracts migrating fish. More research to understand the impacts of sedimentation at the mouth of tributaries is important to evaluate its effects on CWR quality.

Table 7-1 provides a general overview of the snapshots, describing key watershed characteristics and recommendations for protecting and restoring CWR. The recommended actions in ***Table 7-1*** can be generally applied to all CWR, however, actions are highlighted in watersheds where watershed plans and EPA analysis have identified they are most needed. The table also includes a temperature-based classification of CWR quality based on optimal and sub-optimal water temperatures for fish from EPA's Region 10 Temperature Guidance (Appendix 12.20):

- *"Good" cold water refuge* – Average August tributary temperatures cooler than 16˚C.
- *"Average" cold water refuge* - Average August tributary temperatures 16-18˚C.
- *"Marginal" cold water refuge* - Average August tributary temperatures greater than 18˚C.

Table 7-1 Location and characteristics of primary cold water refuges

	Watershed Characteristics				Actions to Protect and Restore CWR			
River Name and CWR Quality	Location/ River Mile	Headwaters	Percent Forested	Dams	Restore Stream Morphology	Limit New Water Withdrawals	Maintain/Restore Riparian Shade	Address Sedimentation at Mouth
Cowlitz River (average)	Below Bonneville Dam (RM 65.2)	Mt. Rainier and Mt. St. Helens	62%	X	X		X	
Lewis River (average)	Below Bonneville Dam (RM 84.4)	Mt. Rainier and Mt. St. Helens	66%	X	X	X	X	
Sandy River (marginal)	Below Bonneville Dam (RM 117.1)	Mt. Hood	77%	X	X		X	
Tanner Creek (good)	At Bonneville Dam (RM 140.9)	Mt. Hood National Forest	87%		X		Fire	
Eagle Creek (good)	Between Bonneville Dam and The Dalles Dam (RM 142.7)	Mt. Hood National Forest	90%		X		Fire	
Herman Creek (good)	Between Bonneville Dam and The Dalles Dam (RM 147.5)	Mt. Hood National Forest	98%		X		X	X
Wind River (good)	Between Bonneville Dam and The Dalles Dam (RM 151.1)	Gifford Pinchot National Forest	84%		X	X	X	X
Little White Salmon River	Between Bonneville Dam and	Gifford Pinchot	70%		X		X	

	Watershed Characteristics				Actions to Protect and Restore CWR			
River Name and CWR Quality	Location/ River Mile	Headwaters	Percent Forested	Dams	Restore Stream Morphology	Limit New Water Withdrawals	Maintain/Restore Riparian Shade	Address Sedimentation at Mouth
(good)	The Dalles Dam (RM 158.7)	National Forest						
White Salmon River (good)	Between Bonneville Dam and The Dalles Dam (RM 164.9)	Mt. Adams	66%				X	X
Hood River (good)	Between Bonneville Dam and The Dalles Dam (RM 165.7)	Mt. Hood	62%		X	X	X	
Klickitat River (average)	Between Bonneville Dam and The Dalles Dam (RM 176.8)	Mt. Adams	48%		X	X	X	X
Deschutes River (marginal)	Between The Dalles Dam and John Day Dam (RM 200.8)	Cascade Mountains of Oregon	32%	X	X	X	X	

7.3 COWLITZ RIVER (RIVER MILE 65) – PROTECT AND ENHANCE

Refuge Volume: 1,554,230 m^3 (largest)

Average August Temperature: 16˚C

Distance to Downstream Refuge: N/A

Distance to Upstream Refuge: 19 mi. (Lewis River)

Cold Water Refuge Rating: Average (16-18°C)

Photo 7-1 Cowlitz River

What features make the Cowlitz River an important cold water refuge to protect and enhance?

The Cowlitz River enters the Columbia River at river mile 65, about 3.5 miles south of Longview, Washington. Cowlitz River temperatures in August average 16°C, almost 5°C cooler than the Columbia River's average August temperature of 20.75°C. This makes the Cowlitz River an average CWR (16-18°C).

Photo 7-2 Aerial view of the Cowlitz River; yellow pin denotes upstream extent of refuge

The lower portion of the Cowlitz River is designated for salmonid spawning, rearing, and migration by the Washington Department of Ecology, which assigns a water quality criterion of 17.5°C for maximum water temperatures. The maximum water temperature modeled for the Cowlitz River is 21°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Cowlitz River is on the 303(d) list for temperature impaired waters. The Cowlitz River is the first major tributary upstream of the mouth of the Columbia where migrating salmonids can seek refuge during their migration, using both the mouth and lower portion of the refuge, estimated to be 1.75 miles upstream (yellow pin, ***Photo 7-2***). Of the tributaries along the lower Columbia River, the Cowlitz River has the largest volume of cold water at the confluence in summer months. In August, the Cowlitz River has an average flow of 3,634 cfs, which produces a CWR estimated to be 1,554,230 cubic meters, or

Photo 7-3 Map of the Cowlitz River Basin

approximately 622 Olympic-sized swimming pools. The next available cold water refuge for migrating salmonids leaving the Cowlitz River is 19 miles upstream in the Lewis River.

Introduction to the Cowlitz River Watershed

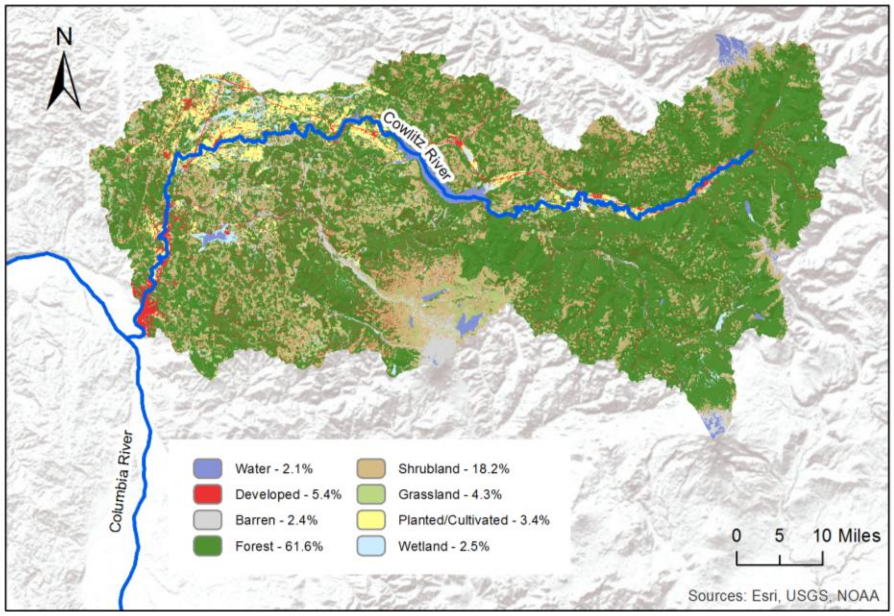


Figure 7-2 Land cover in the Cowlitz Watershed

The Cowlitz watershed drains heavily timbered mountainous slopes surrounding Mount Rainier, Mount Adams, Mount St. Helens, and the Goat Rocks Wilderness. Flowing for 105 miles in a west-southwest direction, the mainstem Cowlitz passes through the cities of Kelso and Longview near its confluence with the Columbia River. Mayfield Dam at River Mile 42 divides the Cowlitz River watershed into an Upper and Lower Basin.

Figure 7-2 and ***Figure 7-3*** show land cover and ownership in the Cowlitz watershed. A large extent of the Upper Basin is in the Mount Rainier National Park and the Gifford Pinchot National Forest. Together the U.S. Forest Service and National Park Service own and manage most of the Upper Basin; in total, public agencies own approximately half of the watershed. Forest covers nearly two-thirds of the watershed – particularly in the Upper Basin where high levels of riparian canopy cover shade headwater streams, helping to maintain cool water temperatures. Shrubland (18%) grows in fragmented patches throughout the watershed. Nearly the entire Lower Basin is privately owned.

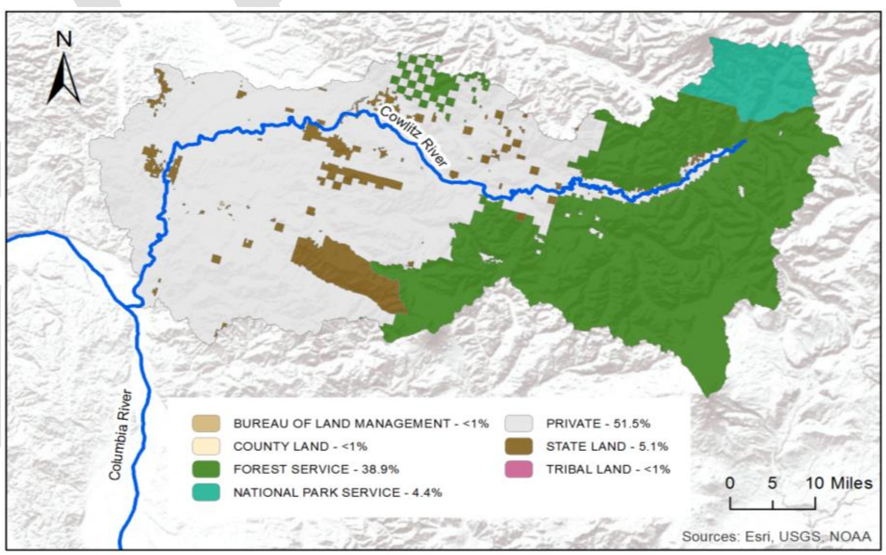


Figure 7-3 Land ownership in the Cowlitz Watershed

Cultivated crops (~3%) and developed areas (~5%) are concentrated along the mainstem below Mayfield Dam and near the river mouth, respectively.

The Toutle River, which enters the Cowlitz at river mile 20, is a major tributary that drains Mount St. Helens. In 1980, the volcano's eruption filled the Toutle Valley with billions of tons of erodible debris. Increased sediment loads can lead to the widening and shallowing of rivers and, as a result, can increase water temperature. The U.S. Army Corps of Engineers constructed sediment retaining dams on the Toutle and continuously dredge the channels of both the Toutle and Cowlitz Rivers.

Factors that Influence Temperature in the Cowlitz River Watershed

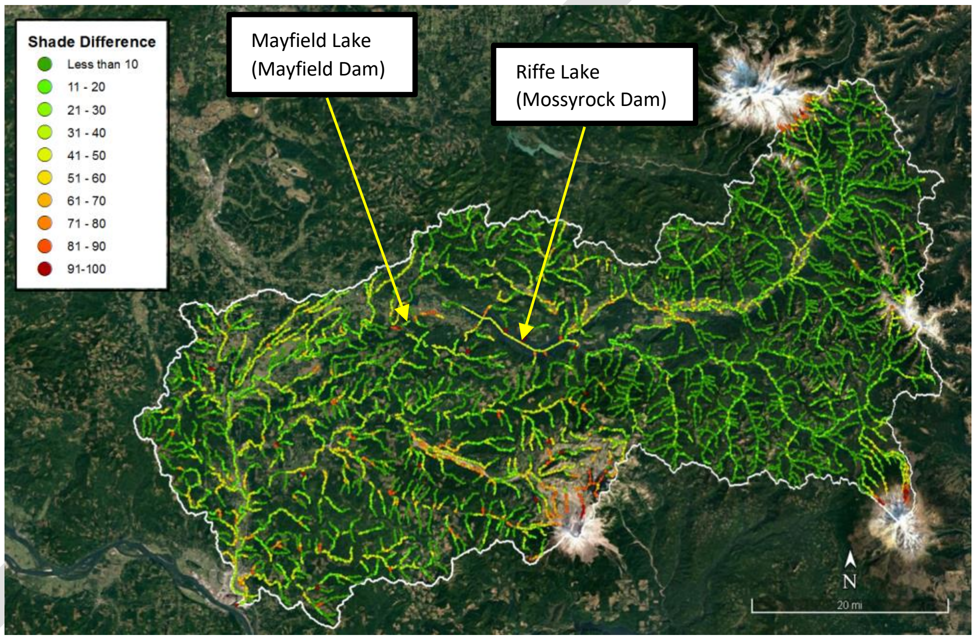


Figure 7-4 Cowlitz River shade difference between potential maximum and current shade

Riparian Vegetation: The Cowlitz River watershed has well-forested areas in the tributaries of the upper watershed. The mainstem Cowlitz River is not as well shaded as its tributaries. The least shaded reaches are those near the confluence with the Columbia River and the reservoirs formed by Mayfield and Mossyrock Dams. The potential to shade the reservoirs is not practical given their large widths. The riparian forests along the lower 20 miles of the Cowlitz River have been severely degraded through industrial and commercial development, and channelization in these areas limits potential for recovery. ***Figure 7-4*** shows the difference between the maximum potential and current shade, demonstrating which areas have the highest restoration potential. Restoration of riparian shade on private forestlands, which cover much of the lower Cowlitz basin, is expected to improve through time and implementation of Washington's State Forest Practice Rules. ***Figure 7-4*** also demonstrates that the mainstem

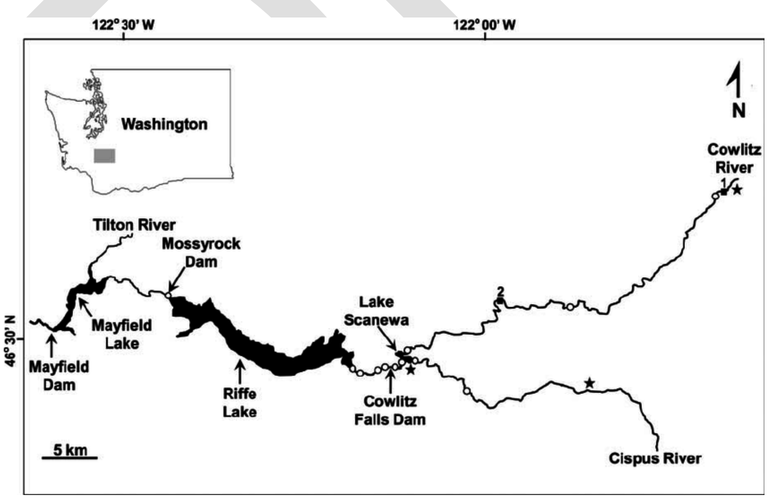


Figure 7-5 Map of Cowlitz River Dams

River above Cowlitz Falls Dam, which has been degraded through timber harvest, has a higher potential for restoration, compared to upper tributaries which lie in protected areas.

Photo 7-4 Cowlitz River as seen from above

Hydromodification: The Cowlitz River is currently modified by three hydroelectric dams in the Upper basin (***Figure 7-5***). Tacoma Power operates the Mossyrock and Mayfield Dams; Bonneville Power Administration operates the Cowlitz Falls Dam. The Mossyrock Dam is the tallest dam in Washington State and forms 23.5-mile-long Riffe Lake. At river mile 52, Mayfield Dam blocks natural passage of anadromous fish. The lower mainstem of the Cowlitz River was channelized to facilitate industrial, agricultural, and urban development. Since Mayfield Dam was built in 1956, however, summer flows in the lower Cowlitz have generally increased, although Tacoma Power often restricts water discharge from the dam to preserve Riffe Lake elevations for recreation opportunities and energy demand in summer months.

Photo 7-5 Sediment retaining structure on the north fork of the Toutle River, which eventually flows to the Cowlitz

Water Use: The Cowlitz River watershed is one of the most intensely farmed basins in western Washington, based on Washington's Department of Ecology's *Water Availability Summary* (2012). Tacoma Power, which operates both dams, has senior water rights in the region. Currently there are no instream flow rules (water rights to protect fish), and the lower mainstem of the Cowlitz is proposed to be left open for new water rights. However, the *Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan* (2010) for the Cowlitz watershed recommends restrictions or closures of new water uses (surface water source limitations) for the mainstem and several tributaries to the Cowlitz River. Overall, WRIA 26 is not facing any immediate or critical water shortages or conflicts. Limiting additional water use will help maintain CWR plume volumes and colder water temperatures.

Climate Change: In 2040, average August temperatures in the Cowlitz River are predicted to rise to 17°C compared to 23ºC in the Columbia River. In 2080, August temperatures in the Cowlitz River are expected to rise further to 18°C compared to 24°C in the Columbia River. Therefore, the Cowlitz River could still be considered a marginal CWR by 2080. However, as temperatures rise, mountain glaciers which help the Cowlitz River stay cool, will recede. Studies at the University of Washington have shown that climate change will likely exacerbate low summer flows in the mainstem Cowlitz River, because of lower snowpack melt in the summer.

Ongoing Activities in the Cowlitz River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

In 2004, the Lower Columbia Fish Recovery Board developed watershed management plans for both the Lower Cowlitz River to meet Endangered Species Act and state requirements for salmon recovery. The management plans detail key priorities contributing to recovery and mitigation in the basin, such as managing regulated stream flows through the hydropower system and restoring floodplain and riparian function. The LCFRB is currently developing the Upper Cowlitz-Cispus Habitat Strategy to recover salmon, steelhead, and bull trout populations to healthy, harvestable levels. The report is expected to focus on increased field work to monitor fish and habitat conditions and to develop community outreach plans. Additionally, Cowlitz County and the U.S. Army Corps of Engineers continue to maintain levees and flood control in the river to regulate legacy sediment contributions caused by the Mount St. Helens eruption. In 2013, USACE initiated a $4.5 million project to construct a sediment retention structure on the Toutle to prevent further sediment seepage into mainstem Cowlitz River.

The Capitol Land Trust manages a 17-acre land parcel along the lower Cowlitz River, including 1,500 feet of streambank which protects and maintains critical habitat for salmonids and other wildlife species.

As the largest CWR used by migrating salmonids, the Cowlitz River is an important refuge to enhance and protect. Actions to protect and enhance the Cowlitz River CWR include:

- Implement actions in the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* (1990) and its amendments on federal forest lands in the upper watershed, including the establishment of Riparian Reserves.
- Implement under Washington State Forest Practice Rules for riparian management on state and private forest lands.
- Implement actions from the *Lower Cowlitz Watershed Management Plan in the Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan* (2010) related to flow and habitat restoration and protection.
- Consider flow, temperature, and habitat restoration and protection recommendations in the Upper Cowlitz-Cispus Habitat Strategy under development that affect downstream temperatures.
- Continue sediment removal on the Toutle River to prevent excess sedimentation at the confluence of the Cowlitz River.
- Continue to develop state and local partnerships with local land trusts, like the Capitol Land Trust, to obtain and preserve pieces of land to keep riparian cover intact in degraded areas.

7.4 LEWIS RIVER (RIVER MILE 84) - PROTECT AND ENHANCE

Photo 7-6 Lewis River looking upstream towards railroad bridge

Refuge Volume: 613,455 m^3 (4^{th} largest)

Average August Temperature: 16.6°C

Distance to Downstream Refuge: 19 mi. (Cowlitz River)

Distance to Upstream Refuge: 33 mi. (Sandy River)

Cold Water Refuge Rating: Average (16-18°C)

Photo 7-7 Aerial View of Lewis River at the Confluence with Columbia River; yellow pin denotes upstream extent; Photo: Google Earth

What features make Lewis River an important cold water refuge to protect and enhance?

The Lewis River, located at river mile 84.4 of the Columbia River, provides a significant CWR below Bonneville Dam. Average August water temperatures in the Lewis River are estimated to be 16.6°C, approximately 5°C colder than the Columbia River. This classifies the Lewis River as an average CWR (16-18ºC). The Lewis River CWR is 19 miles upstream of the Cowlitz River CWR. The Lewis River CWR includes the confluence area and an estimated 1.7 miles upstream (yellow pin, ***Photo 7-7***).

Photo 7-8 Lower Lewis River Falls

The Washington Department of Ecology designates the lower portion of the Lewis River for salmonid spawning, rearing, and migration and assigns a water quality criterion of 17.5°C for maximum water temperatures. The maximum water temperature modeled for the Lewis River is 20.8°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Lewis River is on the 303(d) list for temperature impaired waters. The Lewis River's relatively high discharge averages 1,291 cfs in August. The Lewis River CWR, including the lower portion of the river and the plume, is estimated to be 613,455 cubic meters, the fourth largest refuge in the Columbia River and the size of approximately 245 Olympic-sized swimming pools. Fall Chinook salmon and steelhead trout leaving the Lewis River will swim 33 miles before reaching the next refuge in the Sandy River.

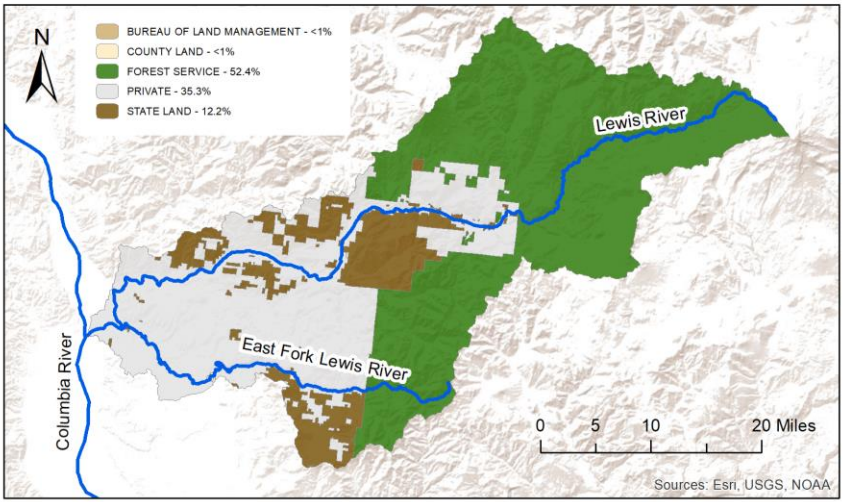


Figure 7-6 Lewis River land ownership

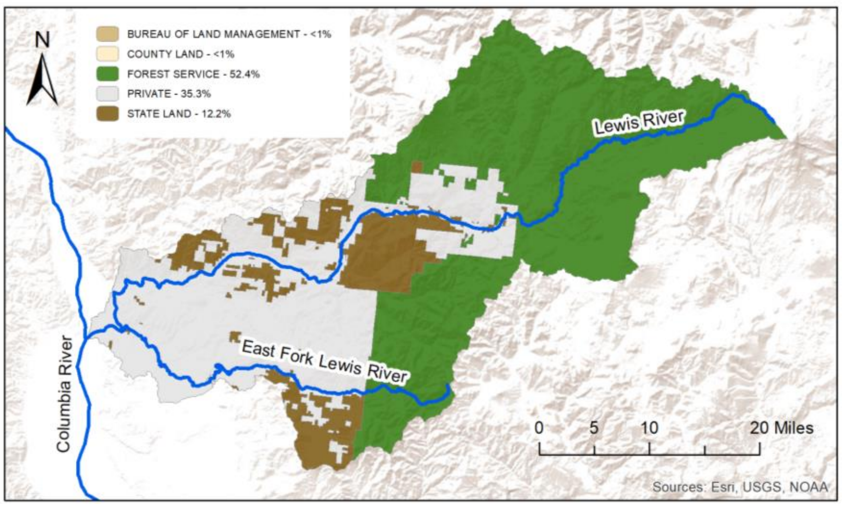


Figure 7-7 Lewis River land cover

Introduction to the Lewis River Watershed

The Lewis River watershed drains the southern slopes of Mount St. Helens and the western flank of Mount Adams. For most of its journey, the Lewis River is synonymous with the North Fork Lewis River. The smaller East Fork joins the North Fork to form the mainstem Lewis River 3.5 miles above the confluence with the Columbia River.

Both forks of the Lewis River have steep, heavily forested headwaters in the Gifford Pinchot National Forest managed by the U.S. Forest Service (***Figure 7-6***). The North Fork begins on the western slope of Mount Adams, while the East Fork Lewis originates near Green Lookout Mountain in the southern portion of the watershed. Approximately two-thirds of the entire watershed is forested. Shrubland (15%) and grassland (5%) are found in fragments throughout the basin. In its last 12 miles, the Lewis River flows through a broad valley predominated by cultivated crops (4%) and urban development, including the City of Woodland and the rapidly-growing community of Battle Ground (***Figure 7-7***). The East Fork Lewis River is impaired for temperature with exceedances of maximum water temperatures of 16ºC, the water quality criteria for core salmonid habitat.

A series of dikes along the lower 7 miles of the Lewis River protect farmland and urban development. The dikes and associated channel modifications are estimated to have disconnected the river from more than half of its historic floodplain.

Factors that Influence Temperature in the Lewis River Watershed

Protecting and Enhancing Riparian Vegetation: Shade levels are high on most of the upper tributaries of the North Fork Lewis River, but shade levels are significantly lower in its middle reaches (***Figure 7-8***). The lowest levels of shade are found on the impounded sections of the

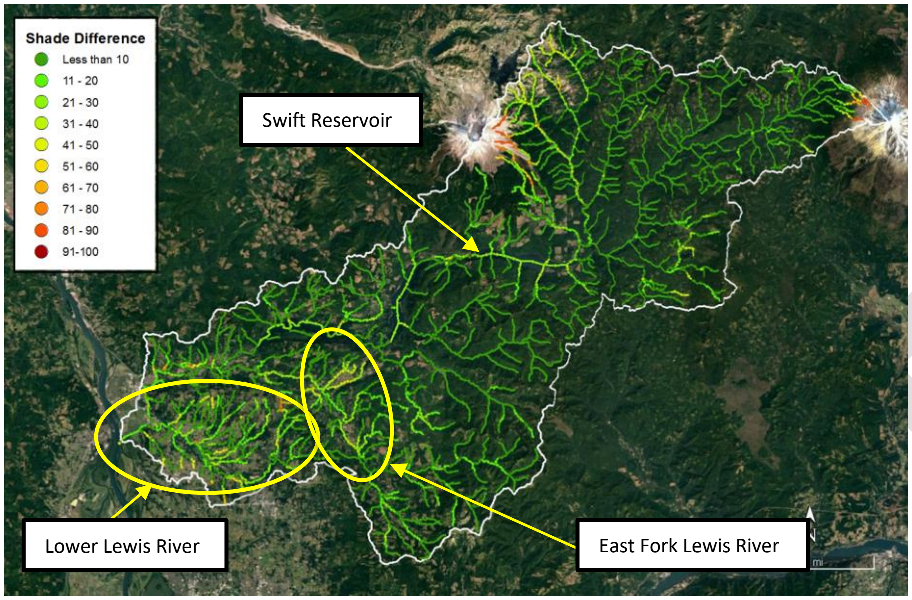


Figure 7-8 Lewis River shade difference between potential maximum and current shade

mainstem Lewis River (Swift Reservoir, see ***Figure 7-8***), where the reservoir is much wider than the stream would be, inhibiting the ability of riparian vegetation to shade the water surface. ***Figure 7-8*** shows that overall stream shade is close to its potential or in reasonable shape, with portions of the lower reaches having the greatest potential for stream shading. The *2010 Washington Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan* noted poor riparian conditions on the mainstem between the mouth and river mile 15. Further, the East Fork Lewis is currently listed as impaired for temperature. Having already developed a Quality Assurance Project Plan, Washington Department of Ecology is scheduled to develop a watershed action plan for temperature for the East Fork Lewis in 2019.

Dams and Hydromodifications: PacifiCorp operates three dams on the North Fork Lewis that have substantial impact on anadromous salmon: Merwin (1931), Yale (1953), and Swift (1958). Merwin Dam, the most downstream structure, blocks passage for anadromous fish at river mile 19.5. The most significant impacts to the CWR are alterations of the natural hydrograph and attendant impacts to channel geometry. Together the altered flow regime and channelization of the Lewis River in downstream reaches contribute to elevated stream temperatures by inhibiting overbank flows that otherwise would have entered groundwater. The dams do, however, release water to benefit fall fish runs, especially during dry years. In the past, operators at Merwin Dam have cut daily water releases in August by about 30 percent to conserve water for fall fish runs, dropping the river stage by almost four inches as a result. Water releases from Merwin Dam are subsurface, taken from Merwin Reservoir at a fixed depth of 150 feet below the surface when the reservoir is at full pool, meaning the dam delivers relatively cool, stable flows in August. Because the dam releases are cooler than inflows, Merwin Dam may help contribute to increased availability of cooler water at the mouth of the tributary.

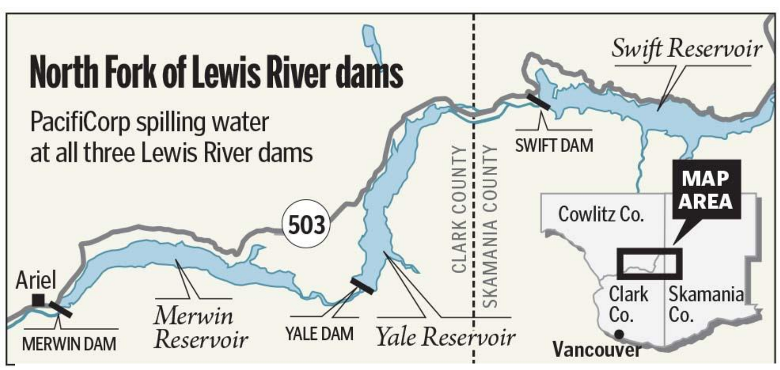


Photo 7-9 Map of Lewis River dams

Water Use: Senior water rights for PacifiCorp to maintain reservoir levels in Lake Merwin and Yale Lake limit the water available for new sources in the

Lewis River. In addition, farms on the lower Lewis River hold surface water rights for irrigation. Since snowpack is depleted in the summer, the demands for water are greatest when the supply is lowest, the same time that migrating salmon use the Lewis River mouth as a refuge.

Photo 7-10 North Fork Lewis River at Cedar Creek, looking downstream

Washington Department of Ecology has assigned instream flow rules (water rights to protect fish) at several locations in the basin. Minimum instream flows at river mile 19 of the Lewis River range from 1,200-2,700 cfs between June-August. For the East Fork Lewis River, minimum instream flows at river mile 10.1 in the summer range from 122-420 cfs. There are also areas within each basin where additional flow withdrawals are not allowed, indicating water use is highly regulated because of the lack of water during times of greatest need.

Climate Change: In 2040, August temperatures in the Lewis River are projected to rise to 18˚C, compared to 23˚C in the Columbia River. In 2080, August temperatures are expected to further rise to 19˚C compared to 24˚C in the Columbia River. Therefore, increases in Lewis River temperatures are expected to shift the refuge from an average quality refuge (16-18˚C) to a marginal quality refuge (>18˚C). Still, the Lewis River is expected to be 5˚C cooler than temperatures in the Columbia River in the summer, even under climate change projections.

Photo 7-11 Lewis River looking towards the Columbia River

Ongoing Activities in the Lewis River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

In the last 10 years, groups such as Clark County, Clark County Conservation District, Cowlitz Indian Tribe, non-profit organizations, private citizens, and state and federal agencies have identified and prioritized projects in the Lewis River. Recent plans include the *Washington Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan* (2010) and the *Lower East Fork Lewis River Habitat Restoration Plan* (2009). The Washington Department of Ecology is developing a watershed plan to address high levels of coliform bacteria and temperature in the East Fork Lewis River. Both plans provide excellent analysis and recommendations for prioritized restoration actions in the watershed. The 2010 plan meets Endangered Species Act and state habitat and salmon recovery requirements. Recommended actions include mitigating the effects of diking and channelization, increasing water discharge from dams in times of low flow, and increasing riparian protections.

Actions to protect and enhance the Lewis River CWR include:

- Implement actions in the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* (1990) and its amendments on federal forest lands, including the reestablishment of Riparian Reserves in the East Fork and North Fork Lewis headwaters.

- Implement Washington's Forest Practice Rules on state and private forests on the lower Lewis River, as noted in the W*ashington Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan* appendix on the Lewis River. This includes road maintenance and bank stabilization to reduce sediment build-up at the confluence.
- Continue to provide or enhance cool summer flows from Merwin Dam to maintain the CWR volume and temperatures.
- Continue implementing instream flow rules, and other minimum instream flow recommendations from the W*ashington Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan.*
- Increase riparian shading, specifically between river mile 0-15 where potential for shading is highest, as noted in the 2009 and 2010 Lewis River plans.
- Consider including actions in the East Fork Lewis River watershed plan under development for temperature that maintain high flows and cold temperatures downstream in the lower Lewis River.

7.5 SANDY RIVER (RIVER MILE 117) – PROTECT AND ENHANCE

Refuge Volume: 31,915 m^3 (10th largest)

Average August Temperature: 18.8˚C

Distance to Downstream Refuge: 33 mi. (Lewis River)

Distance Upstream Refuge: 24 mi. (Tanner Creek)

Cold Water Refuge Rating: Marginal (>18ºC)

Photo 7-13 Upper Sandy River

Photo 7-12 Aerial view of Sandy River delta at the confluence with Columbia River; yellow pin denotes upstream extent

What features make the Sandy River an important cold water refuge to protect and enhance?

The Sandy River is located at river mile 117 of the Columbia River, downstream of the Bonneville Dam. Sandy River temperatures in August are 2.5°C cooler than the Columbia River, averaging 18.8°C. This makes the Sandy a marginal CWR (>18˚C) for migrating salmonids. The Sandy CWR is 33 miles upstream of the Lewis River CWR. ODEQ assigns a water quality criterion of 18°C for maximum temperatures to protect salmonid rearing and migration in the lower portion of the Sandy River. The maximum water temperature modeled for the Sandy River is 23.6°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Sandy River is on the 303(d) list for temperature impaired waters. Migrating salmon are thought to use the confluence of the rivers and an estimated 1.10 miles up the Sandy River as a CWR (yellow pin, ***Photo 7-12***). The Sandy River mainstem is currently undammed from the headwaters to the confluence, helping temperatures stay cooler with a more natural flow regime. However, historical lahars (fast-moving mudflows) formed a large debris fan with a braided channel in the lower reaches and mouth of the Sandy River. Further, the glacier that feeds the Sandy River is heavily laden with sediment. Sediment build-up at the mouth can make the refuge shallower and subsequently warmer over time. The Sandy River is the tenth largest CWR in the Lower Columbia River with an estimated volume of 31,915

Photo 7-14 Sandy River at Dodge Park, upstream of confluence

m^3, the size of approximately 13 Olympic-sized pools, and a mean flow of 469 cfs. The next upstream CWR is 24 miles away in Tanner Creek.

Introduction to the Sandy River Watershed

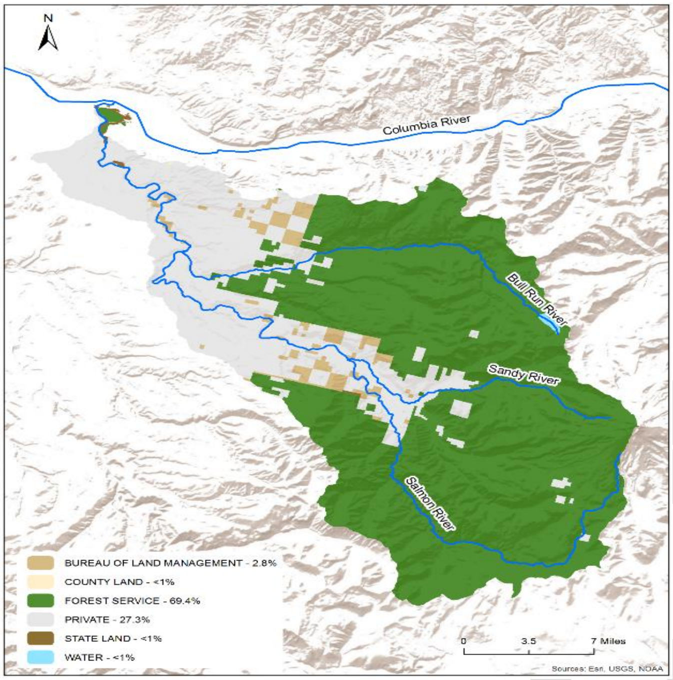


Figure 7-9 Sandy River land ownership

Glaciers on the western slopes of Mount Hood feed the Sandy River. Much of the upper basin is protected as part of the Mount Hood National Forest and remains heavily forested. The Sandy River watershed includes the Bull Run River sub-basin, Portland's drinking water source. Given its proximity to the Portland metropolitan area and its high quality natural areas, the Sandy River watershed is a popular recreation area. Approximately 25 miles of the Sandy River is designated as a federal Wild and Scenic River and state Scenic Waterway. The Wild and Scenic designations and the Bull Run River watershed's status as an important drinking water source provide protections by limiting development in the middle and upper watersheds.

Approximately three-quarters of the watershed is forested, predominately in the Mount Hood National Forest which makes up about 2/3 of the watershed (***Figure 7-9*** and ***Figure 7-10***). The lower watershed is mostly privately owned. The flat topography of the lower watershed supports a mix of cultivated crops (4%) and the cities of Gresham and Troutdale, the only significant areas of developed land other than State Highway 26, which winds through the watershed before passing south of Mount Hood.

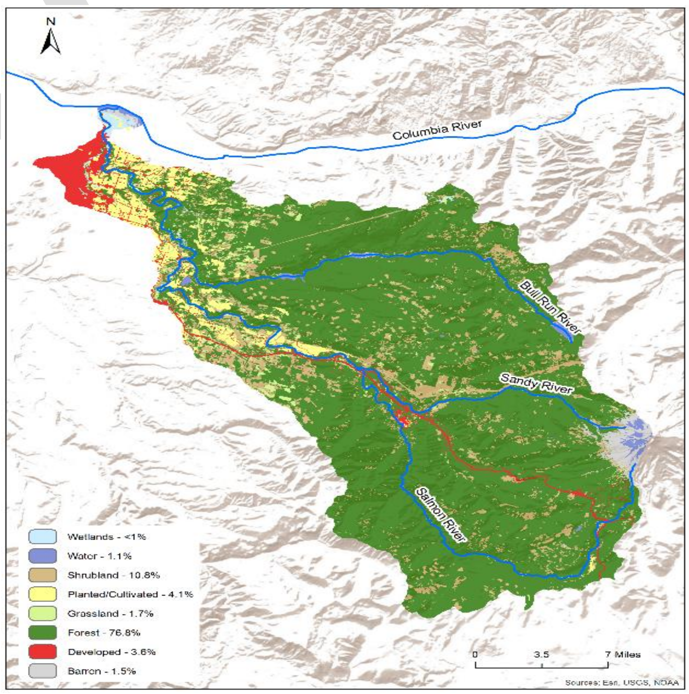


Figure 7-10 Sandy River land cover

Factors that Influence Temperature in the Sandy River Watershed

Protecting and Enhancing Riparian Vegetation: The Sandy River watershed has high levels of riparian shade throughout the upper and middle forested tributaries. These are on federal,

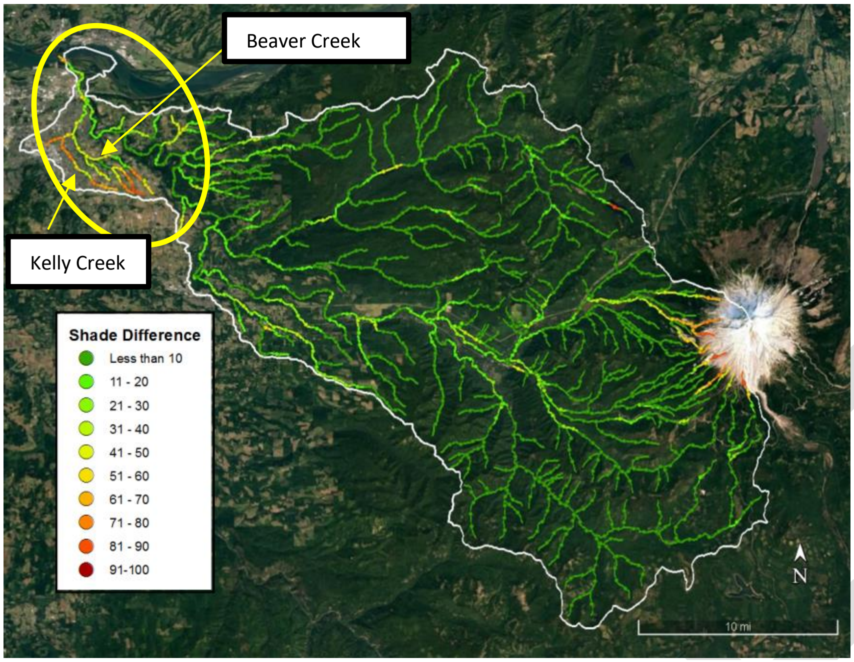


Figure 7-11 Sandy River shade difference between potential maximum and current shade

state, and private lands that are governed by the *USFS Mount Hood Forest Land and Resource Management Plan* (1990), and other plans. This shade serves to block solar radiation and maintain cool stream temperatures. However, there are reaches that have been degraded and have potential for increased shade in the lower Sandy River. Shade from riparian vegetation reduces solar exposure to the stream channel and helps maintain cool water temperature. ***Figure 7-11*** shows the difference between maximum and current shade levels highlighting the reaches that could benefit the most from riparian revegetation. Beaver and Kelly Creeks, tributaries to the lower Sandy River, have the greatest potential for more riparian shade.

Water quality modeling in ODEQ's *Sandy River Basin TMDL* (2005) predicted a temperature increase of approximately 0.5ºC with maximum potential vegetation under low flow conditions. Increased riparian shade can help to reduce sedimentation and maintain CWR volumes and temperatures.

Figure 7-12 Sandy River Delta Dam pre-removal – white line indicates location of former dam (USACE, 2015)

Dams and Hydromodifications: The mainstem Sandy River is currently undammed for 56 river miles from the headwaters to the confluence. The removal of several dams, including Marmot Dam (2007), the Little Sandy Diversion Dam (2008), and the Sandy River Delta Dam (2013) has restored a more natural flow regime, increased floodplain connectivity, and channel complexity. The Sandy River Delta Dam (see ***Figure 7-12***) had blocked the east channel of the delta, impeding fish passage and access. The U.S. Army Corps of Engineers identified habitat improvements from removal of the Sandy River Delta Dam as including year-

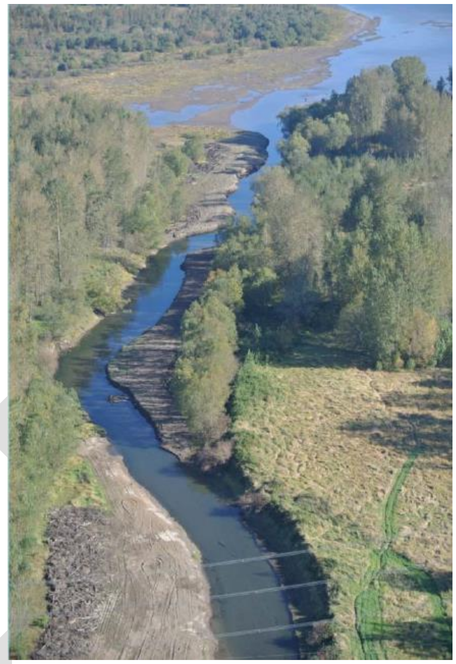


Photo 7-15 East Channel post-Sandy Delta Diversion Dam removal (USACE)

round access for salmon to the east channel, cooler waters in the east channel during the summer, and additional shallow water.

A significant tributary with dams is on the Bull Run River, the drinking water source for the City of Portland. Historically, the unused water from the top of the thermally-stratified Bull Run reservoirs was released to the Bull Run River and warmed temperatures in the Sandy. In the past few years, however, the Portland Water Bureau has used a selective withdrawal system to release higher volumes of colder water in the summer, which has resulted in colder waters reaching the Sandy. This along with other measures in the *Bull Run Water Supply Habitat Conservation Plan* (2008) have helped to reduce harmful effects to salmon from the Bull Run River reservoirs.

The *State of the Sandy* (2017) report by the Sandy River Watershed Council indicates that a dam on Kelly Creek on the Mount Hood Community College campus creates an artificial pond which raises temperatures as much as 4˚C in the summer. The community college is considering removing this dam, which could cool the water temperatures in the lower Sandy watershed. Other dams continue to operate on many tributaries to the Sandy River.

Table 7-2 Water availability analysis, Sandy River at mouth, Oregon Water Resources Department

SANDY RIVER > COLUMBIA R – AT MOUTH (@ 50% exceedance)			
Month	Monthly Streamflow (cfs)		
	Natural Streamflow	Water Allocated or Reserved	% Allocated *
JUNE	1,620	1,932	119%
JULY	950	1,067	112%
AUGUST	633	583	92%
SEPTEMBER	682	730	107%
Top users: Municipal (97%), Domestic (2%)			
* % Allocated: [Water Allocated or Reserved]/[Natural Streamflow].This is the percentage of water either allocated or reserved for in-stream or other uses compared with the natural streamflow. Percentages over 100% indicate the water is overallocated at the mouth of the river.			

Reference: https://apps.wrd.state.or.us/apps/wars/wars_display_wa_tables/display_wa_complete_report.aspx?ws_id=71480&exlevel=50&scenario_id=1

Water Use: The Sandy River is overallocated in June, July, and September. Water availability is limited in the Sandy River in the lower watershed primarily due to Portland's diversion of the Bull Run River for its drinking water. Municipal uses account for 97% of the water use, leaving little water for other uses. Therefore, increased water use may reduce the CWR plume volume and raise temperatures in the river. The *Sandy River Habitat Conservation Plan* establishes habitat conservation measures, including flows, that help maintain CWR plume volumes and cold water temperatures.

Climate Change: In 2040, average August temperatures in the Sandy River are predicted to rise to 20˚C compared to 23˚C in the Columbia River. In 2080, August temperatures in the Sandy are expected to rise further to 21˚C compared to 24˚C in the Columbia River. Therefore, although the Sandy River will still be cooler than the Columbia River by 3˚C in 2040 and 2080, the absolute temperature of the Sandy River will be higher, which decreases its benefit to salmon.

Ongoing Activities in the Sandy River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

Many entities are actively working in the Sandy River Watershed and have completed numerous plans and successful restoration projects throughout the basin. The Sandy River Watershed Council, USFS, Bureau of Land Management, Portland Water Bureau, East Multnomah Soil and Water Conservation District, Lower Columbia Estuary Partnership and many others have collaborated to obtain funding and engage with local communities to complete projects. The Sandy River Watershed Council's *State of the Sandy* report highlights restoration work in the basin, including improving and planting riparian vegetation, conducting large wood placement and channel alteration, and improving fish passage. Ongoing and planned activities, particularly increasing riparian vegetation near the confluence and the removal of the Kelly Creek Dam, could benefit the CWR.

Actions to protect and enhance the Sandy River CWR include:

- Implement actions in the *USFS Mount Hood National Forest Land and Resource Management Plan* and its amendments on federal forest lands in the upper watershed, including the establishment of riparian reserves.
- Implement Oregon's Forest Practices Act on state and private forest lands throughout the watershed.
- Continue implementing actions in the Portland Water Bureau's *Bull Run Water Supply Habitat Conservation Plan* to maintain higher flows, cooler temperatures, and habitat creation and protection.
- Implement ongoing protections from the Wild and Scenic designation in the lower Sandy River.
- Implement riparian planting in Kelly Creek and Beaver Creek as referenced in the *Sandy River Basin TMDL*.
- Continue collaboration in the watershed among multiple interested parties for restoration, increased large woody debris, and other watershed restoration activities.
- Increase flows and cool temperatures by removing Kelly Creek dam as noted in the *State of the Sandy*.
- Support education and outreach opportunities on grant and tax benefits for habitat and riparian restoration on privately-owned properties.

7.6 TANNER CREEK (RIVER MILE 141) – PROTECT AND ENHANCE

Photo 7-16 Tanner Creek drainage from Hamilton Island (2005)

Refuge Volume: 1,713 m^3 (13th largest)

Average August Temperature: 11.7˚C

Distance to Downstream Refuge: 24 mi. (Sandy River)

Distance to Upstream Refuge: 2 mi. (Eagle Creek)

Cold Water Refuge Rating: Good (<16˚C)

What features make Tanner Creek an important cold water refuge to protect and enhance?

Tanner Creek provides a small CWR located immediately below Bonneville Dam at river mile 141, 24 miles upstream of the refuge in the Sandy River. With an estimated average temperature of 11.7°C in August, Tanner Creek is approximately 10°C colder than the Columbia River, classifying the creek as a good quality refuge (<16°C).

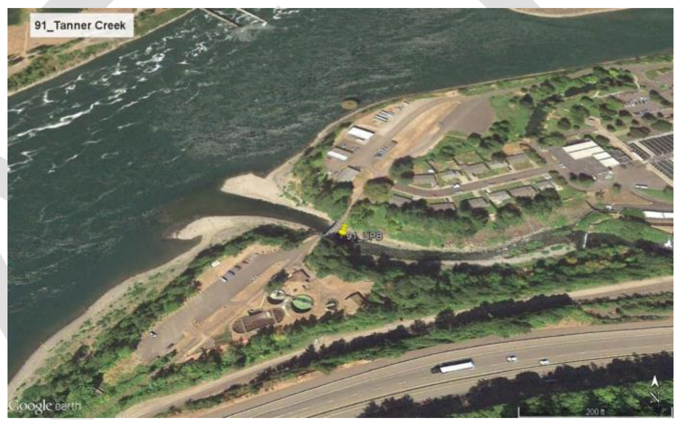


Photo 7-17 Aerial view of Tanner Creek at the confluence with Columbia River; yellow pin denotes upstream extent

ODEQ has designated the lower portion of Tanner Creek for core cold water habitat and salmon and steelhead spawning and has assigned water quality criteria of 16°C and 13°C for maximum water temperatures during spawning (August 15 – May 15), respectively. The maximum water temperature modeled for Tanner Creek is 14.5°C (1993-2011) (Appendix 12.18). However, based on actual maximum temperature readings, the lower portion of Tanner Creek is not on the 303(d) list for temperature impaired waters. Migrating salmonids use both the mouth and the stream channel below Tanner Creek Bridge, and an estimated 0.08 miles upstream, as a refuge (yellow pin, ***Photo 7-17***). While the creek is very cold relative to the Columbia River, the August flow is modest at only 38 cfs. However, the Bonneville Hatchery uses groundwater, which is discharged to Tanner Creek and increases flows below the hatchery. As a result, the CWR is estimated to be 1,713 m^3 in size, or approximately ¾ of an Olympic-sized swimming pool, making it the smallest of the 12 primary refuges on the Lower Columbia River. Returning adults must pass over Bonneville Dam and swim two miles before encountering Eagle Creek, the next primary CWR.

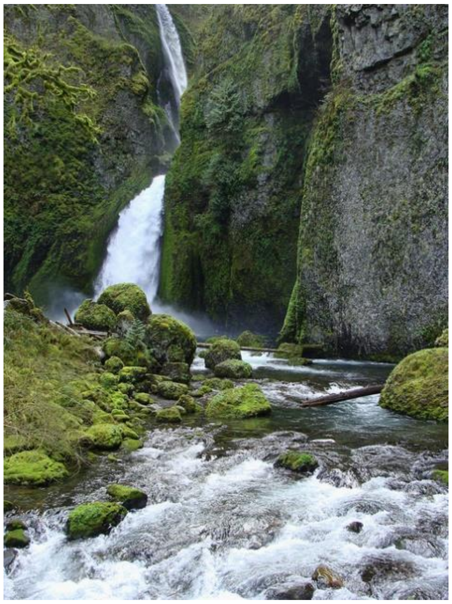


Photo 7-18 Waclella Falls

Introduction to the Tanner Creek Watershed

The watershed lies within the Mount Hood National Forest and Columbia Gorge National Scenic Area. Famous for its picturesque Wahclella Falls, many Gorge visitors have hiked along the creek's lower reaches. The Bull Run watershed, which supplies water to the City of Portland, borders the basin to the southwest; the Eagle Creek watershed abuts Tanner Creek to the east.

Tanner Creek originates from a groundwater spring below Tanner Butte on the southern bank of the Columbia River Gorge. The heavily forested watershed combined with the creek's steep gradient and short length (6.5 miles) produce reliably cold water. Cascading downhill in a nearly due north direction, Tanner Creek collects lateral tributaries from the east and west hillslopes. Protected as part of the Mark O. Hatfield Wilderness Area, no urban development or agricultural land exists in the watershed. Forest (87%) predominates in the basin; shrubland (12%) grows on portions of the upper and middle watershed. Bonneville Fish Hatchery, the only developed site, is located north of Highway 84 adjacent to the creek's confluence with the Columbia River (***Figure 7-13***). The U.S. Forest Service owns and manages the entire watershed except for the State of Oregon's control of Bonneville Fish Hatchery (***Figure 7-14***).

In 2017, the Eagle Creek Fire burned a significant portion of the watershed. Potential post-fire impacts to the refuge include increased water temperatures due to reduced riparian canopy cover and sedimentation of the creek mouth resulting from rainfall on bare, steep slopes.

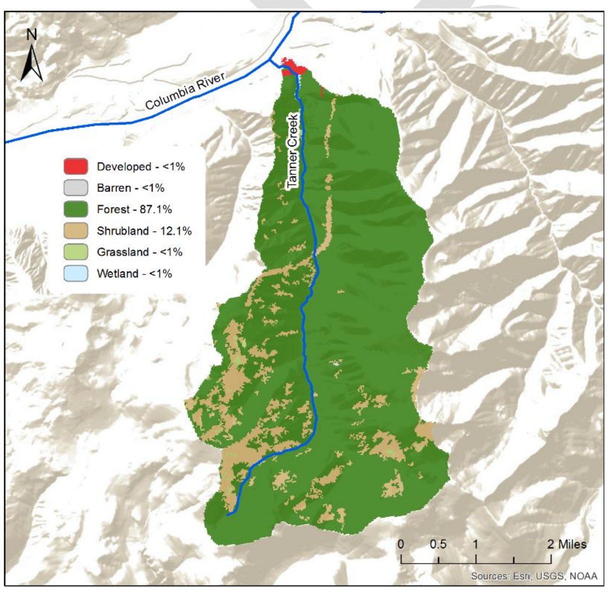


Figure 7-13 Tanner Creek land cover

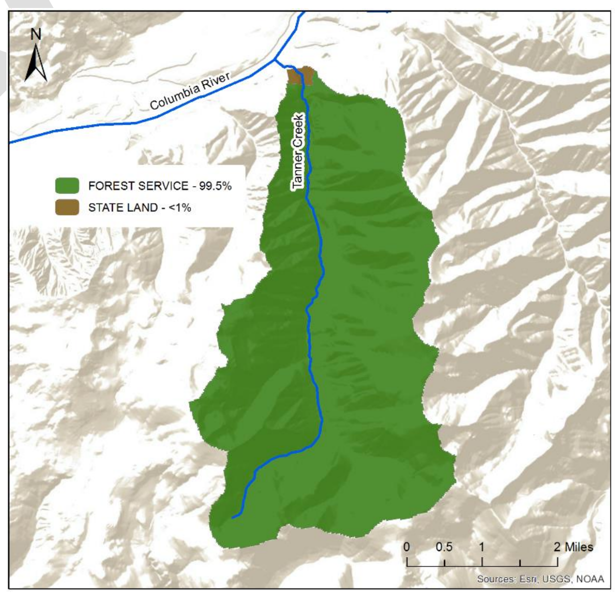


Figure 7-14 Tanner Creek land ownership

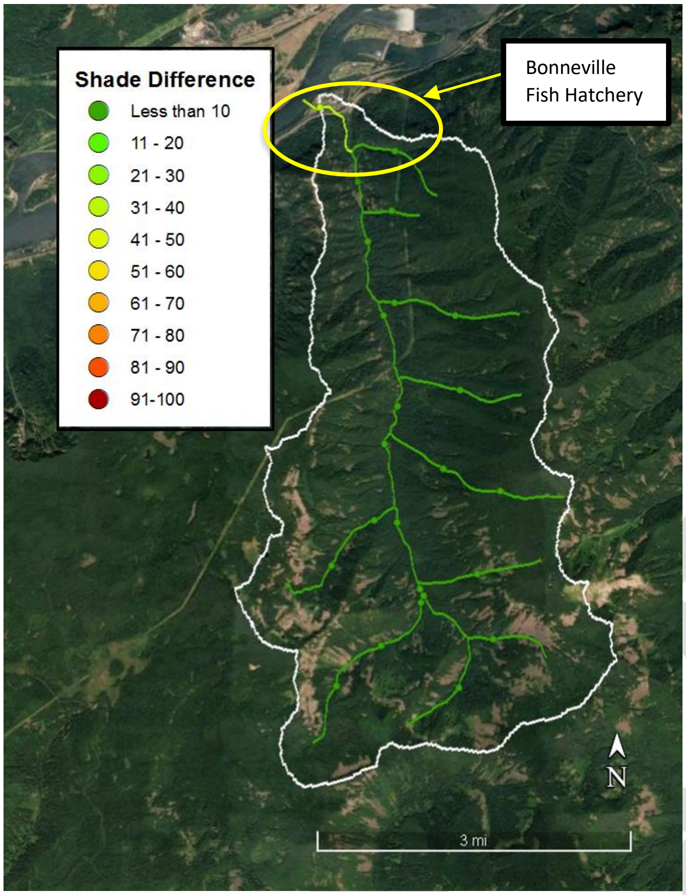


Figure 7-15 Tanner Creek shade difference between potential maximum and current shade

Factors that Influence Temperature in the Tanner Creek Watershed

Protecting and Enhancing Riparian Vegetation*:* Prior to the Eagle Creek Fire, high levels of canopy cover shaded Tanner Creek and its tributaries, except for the lowermost portion of the mainstem channel that has less than 50% cover due to the Bonneville Fish Hatchery.

Areas in the watershed with the highest potential for canopy cover restoration include the mouth of the creek in and around Bonneville Fish Hatchery and along the riparian areas affected by moderate-to-severe fire severity disturbance levels, predominately along the upper portions of lateral tributaries (not shown in ***Figure 7-15***).

Post-fire analysis conducted by the U.S. Forest Service indicated large extents of the mid-basin hillslopes were moderately (yellow) or severely burned (red), meaning the fire consumed at least 80% of the ground cover and surface organic matter (***Figure 7-16***). Fortunately, most of the severe burn areas occurred outside the riparian zone. A GIS analysis of the Burn Severity Assessment data indicated that 14% of the riparian zone suffered low severity fire disturbance, 31% experienced moderate severity disturbance, and 12% experienced high severity disturbance.

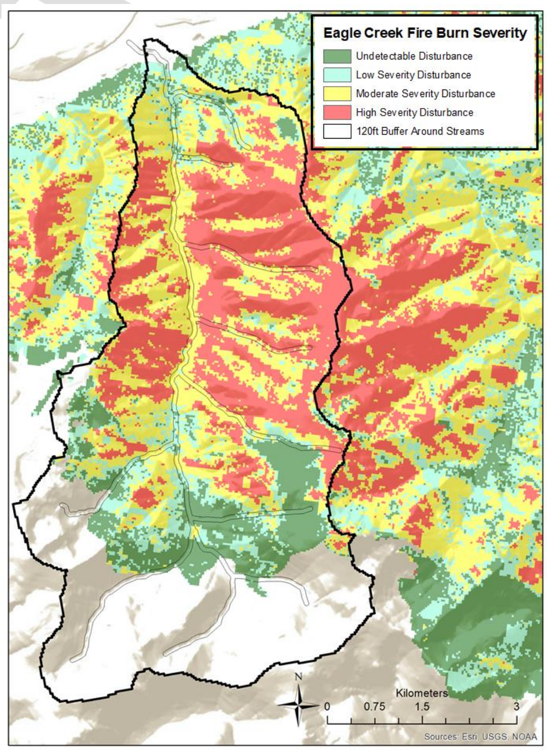


Figure 7-16 Eagle Creek Fire Burn Severity map in the Tanner Creek Watershed. (Peter Leinenbach and USFS)

Dams and Hydromodifications: Except for two small dams on the creek's last mile, the basin's landcover and stream channel retain natural characteristics. The Tanner Creek Intake Dam, 0.3 miles above the creek mouth, is owned and operated by the ODFW in support of Bonneville Fish Hatchery. The upstream dam, located 0.8 miles above the creek mouth, is unnamed and little information exists about its owner, history, and purpose. No known published reports analyze the dams' impacts, but it is unlikely that either structure exerts a strong influence on the creek's hydrology or water temperatures.

Photo 7-19 Tanner Creek

Water Use: The Tanner Creek CWR is not adversely impacted from water withdrawals. Bonneville Fish Hatchery is the only water user in the small watershed. To support fish cultivation, the ODFW owns two year-round water rights: a surface water right that allows for the diversion of up to 50 cfs and a groundwater right that allows for the pumping of an additional 2.2 cfs of water. The diversion and point of use for both water rights is in and around the creek mouth and the majority of pumped or diverted water returns to the stream after being used in the Hatchery. Further, the basin's steep topography and designation as a Wilderness Area limit the potential for new water uses in the future.

Climate Change: In 2040, Tanner Creek's average August water temperature is projected to increase to 13°C while the mainstem Columbia River is projected to average 23°C. In 2080, average August water temperature in Tanner Creek is expected to rise by an additional degree to 14°C compared to 24°C in the Columbia River. Therefore, while water temperatures are projected to increase in future decades, Tanner Creek is predicted to provide a small plume of good quality refuge (<16°C) for migrating salmonids, even under climate change projections.

Photo 7-20 Tanner Creek Drainage post Eagle Creek Fire (USFS)

It is important to note that temperature modeling of Tanner Creek occurred prior to the Eagle Creek Fire. Post-fire restoration work will be critical to ensure that the creek's water temperatures stay at or below the projected levels.

Ongoing Activities in the Tanner Creek Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

Tanner Creek's small size and absence of residents make it one of the few watersheds in Oregon without an established watershed council to coordinate restoration and outreach activities. As a result, there is a lack of information on recommended actions or current protection and enhancement projects in the watershed.

Post-fire restoration work could include projects to restore canopy cover in moderately-to-severely burned riparian reaches as well as slope stabilization efforts to mitigate landslides and increased sedimentation of the creek mouth resulting from precipitation on bare, steep slopes.

Since nearly the entire Tanner Creek watershed is protected as part of the Mark O. Hatfield Wilderness Area and the Columbia River Gorge Scenic Area, the basin is not at risk of new development and, as a result, is in good position to maintain cold water temperatures in the future. Actions to protect and enhance the Tanner River CWR include:

- Consider special designations, antidegradation policies, and/or narrative water quality criteria as appropriate to prevent warming of the creek above current temperatures and maintain existing flows.
- Implement post-fire restoration activities to stabilize sediment and promote riparian forest regrowth.
- Increase levels of riparian shading in the lower mainstem reaches in and around Bonneville Fish Hatchery and in moderately-to-severely burned riparian reaches.
- Monitor and manage the creek mouth for excessive levels of post-fire sedimentation.

7.7 EAGLE CREEK (RIVER MILE 143) – PROTECT AND ENHANCE

Refuge Volume: 2,988 m^3 (12th largest)

Average August Temperature: 15.1°C

Distance to Downstream Refuge: 2 mi. (Tanner Creek)

Distance to Upstream Refuge: 4.5 mi. (Herman Creek)

Cold Water Refuge Rating: Good (<16°C)

Photo 7-21 Eagle Creek confluence facing Columbia River (Courtesy photo: Jonnel Deacon)

What features make the Eagle Creek an important cold water refuge to protect and enhance?

Photo 7-22 Aerial view of Eagle Creek confluence with Columbia River; yellow pin denotes upstream extent

Located at river mile 143 in Oregon, Eagle Creek is approximately halfway between the Pacific Ocean and the Snake River. It is the first CWR tributary salmon encounter upstream of the Bonneville Dam. The confluence of Eagle Creek emerges from a narrow channel, becomes shallow and broad, flows south past Interstate 84, and enters the Columbia River. Eagle Creek temperatures in August are 6°C cooler than the Columbia River, with average temperatures of 15.1°C. This classifies Eagle Creek as a good CWR (<16˚C). ODEQ designates the lower portion of Eagle Creek for salmonid rearing and migration and has assigned a water quality criterion of 18°C for maximum water temperatures. The maximum water temperature modeled for Eagle Creek is 18.8°C (1993-2011) (Appendix 12.18). However, based on actual maximum temperature readings, the lower portion of Eagle Creek is not on the 303(d) list for temperature impaired waters. Eagle Creek is the first among a cluster of eight CWR between Bonneville Dam and The Dalles Dam. Migrating fish use the confluence and an estimated 0.15 miles upstream of the confluence as CWR (yellow pin, ***Photo 7-22***).

Eagle Creek has a mean flow of 72 cfs in August, and the twelfth largest CWR in the Columbia River, estimated at 2,988 m^3, slightly larger than one Olympic-sized swimming pool. Though Eagle Creek provides a smaller CWR compared to others, it presents a reliably colder stream of water on average compared to the Columbia River. The next available CWR is 4.5 miles upstream in Herman Creek.

Photo 7-23 Eagle Creek confluence facing west (Courtesy Photo: Jonnel Deacon)

Introduction to the Eagle Creek Watershed

The Eagle Creek watershed drains north-facing slopes of the Columbia River's southern bank, immediately upstream of Bonneville Dam. Prior to the 2017 Eagle Creek Fire that originated in the watershed, the Eagle Creek Trail was the most popular hiking trail in the Columbia Gorge. Many visitors have hiked to Metlako and Punch Bowl Falls and beyond into the Mark O. Hatfield Wilderness Area within the Mount Hood National Forest.

The U.S. Forest Service manages nearly the entire watershed except for the State of Oregon's control of the Cascade Hatchery near the creek mouth (***Figure 7-17***). The watershed retains natural vegetation – a mix of forest (89%) and shrubland (9%) cover the steep slopes (***Figure 7-18***). The fish hatchery and group campground at the creek mouth are the only developed areas in the basin.

In September 2017, the Eagle Creek Fire spread from the watershed and burned tens of thousands of acres in the Columbia Gorge. In the context of CWR, it is crucial to collect more information on the impacts of the fire on riparian vegetation, channel banks, erosion, and corresponding effects on water temperature and quality.

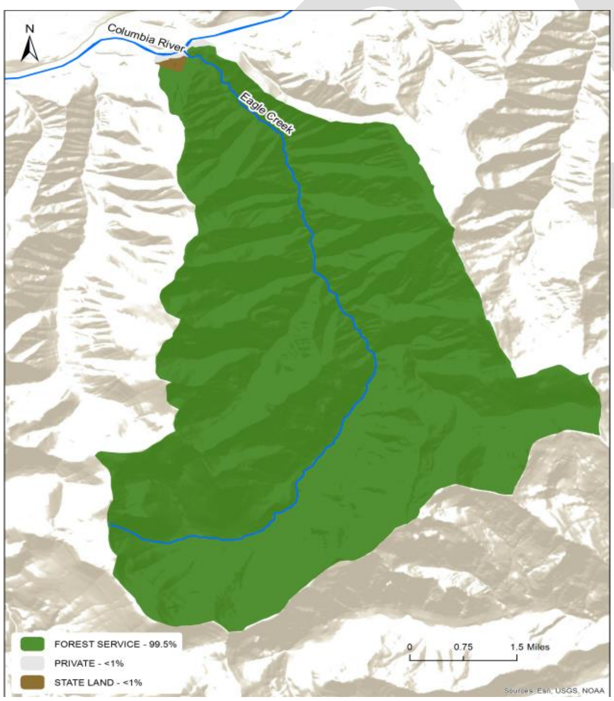


Figure 7-17 Eagle Creek ownership

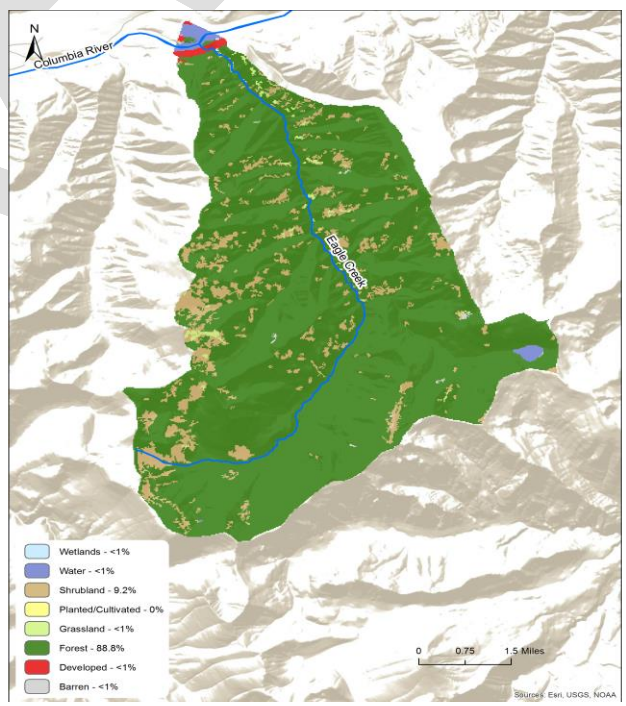


Figure 7-18 Eagle Creek land cover

Factors that Influence Temperature in the Eagle Creek Watershed

Protecting and Enhancing Riparian Vegetation*:* Prior to the Eagle Creek Fire, large amounts of riparian vegetation cover shaded Eagle Creek and its tributaries except for portions of middle and lower Eagle Creek. ***Figure 7-19*** compares the shade differences between the potential maximum and current shade pre-2017 Eagle Creek Fire.

Post-fire analysis conducted by the U.S. Forest service indicated large extents of Eagle Creek were moderately (yellow) or severely burned (red) in tributaries to Eagle Creek and middle and upper Eagle Creek, meaning the fire consumed at least 80% of the ground cover and surface organic matter (***Figure 7-20***). Much of the riparian zone corridor along lower Eagle Creek, however, experienced "undetectable disturbance" in terms of loss of vegetation. A GIS analysis of the Burn Severity Assessment data indicated that 23% of the riparian zone suffered low severity fire disturbance, 24% experienced moderate severity disturbance, and 5% experienced high severity disturbance.

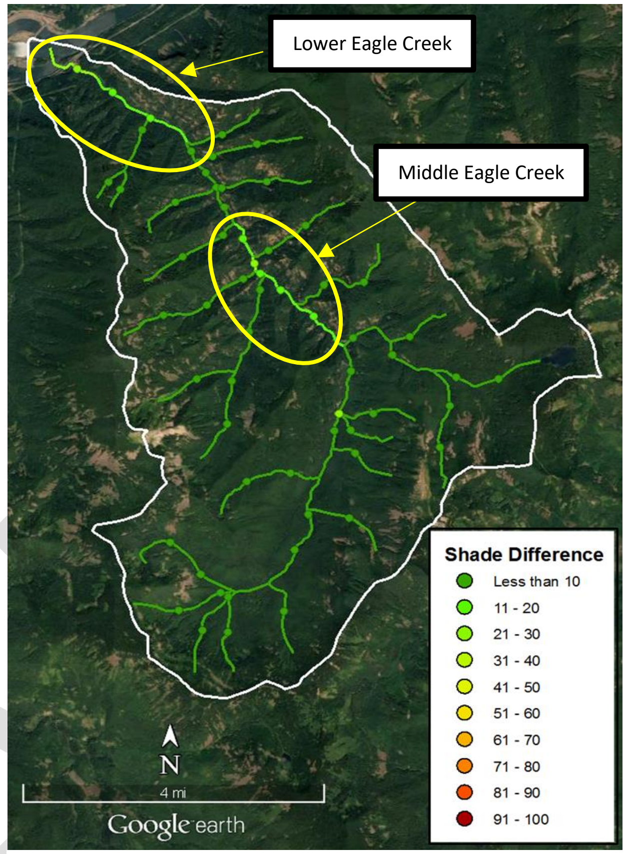


Figure 7-19 Eagle Creek shade difference between potential maximum and current shade

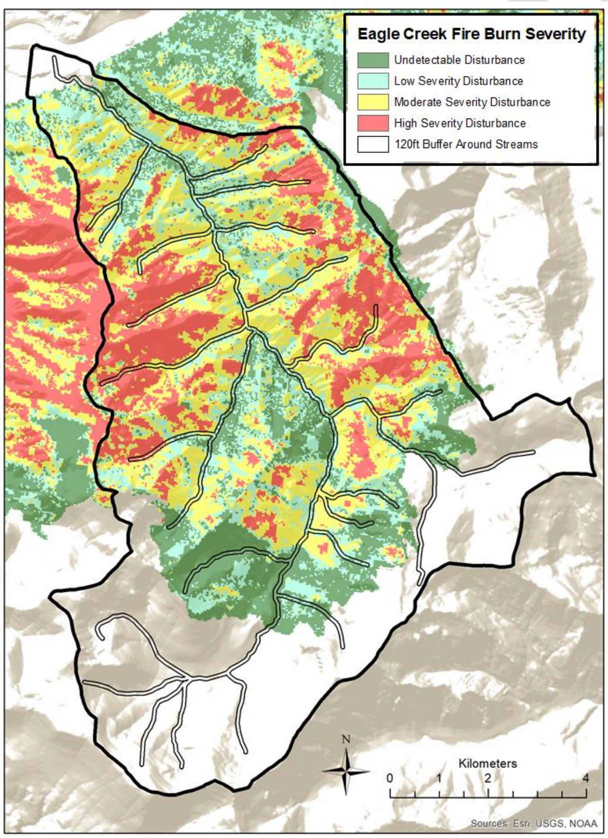


Figure 7-20 Eagle Creek Fire Burn Severity map in the Eagle Creek Watershed (Peter Leinenbach and USFS)

Dams and Hydromodifications. There are no dams in the Eagle Creek watershed. New dams or hydromodifications in Eagle Creek that would heat water downstream in the summer or significantly reduce channel complexity would harm the Eagle Creek CWR.

EAGLE CREEK > COLUMBIA R – AT MOUTH HOOD BASIN (@50% exceedance)			
Month	Monthly Streamflow (cfs)		
	Natural Streamflow	Water Allocated or Reserved	% Allocated*
JUNE	158	0	0%
JULY	78.7	0	0%
AUGUST	54.8	0	0%
SEPTEMBER	52.5	0	0%
Top three users: None			
Water net positive: Year round			
*% Allocated:[Water Allocated or Reserved]/[Natural Streamflow]. This is the percentage of water either allocated or reserved for in-stream or other uses compared with the natural streamflow. Percentages over 100% indicate the water is overallocated at the mouth of the river.			
Reference: http://apps.wrd.state.or.us/apps/wars/wars_display_wa_tables/MainMenu1.aspx			

Table 7-3 Water Availability Analysis, Eagle Creek at mouth, 8/21/17, Oregon Water Resources Department

Climate Change. In 2040, average August temperatures in Eagle Creek are predicted to be 17°C compared to 22°C in the Columbia River. In 2080, August temperatures in Eagle Creek are expected to rise further to 18°C compared to 23°C in the Columbia River. Therefore, Eagle Creek is expected to shift from a good CWR (<16°C) to an average CWR (16-18°C), unless restoration actions such as increased riparian vegetation offset increasing water temperatures. Eagle Creek is still expected to be more than 5°C cooler than temperatures in the Columbia River in the summer, even under climate change projections.

Water Use: There are no consumptive or instream uses at the mouth of Eagle Creek. Thus, the net stream availability is the same as the natural streamflow. The water availability analysis from the Oregon Water Resources Department indicates water is available in Eagle Creek. At river mile 2, the ODFW has a surface water right to divert up to 45 cfs for the Cascade Hatchery and return the water just downstream of the hatchery at the mouth of Eagle Creek. This has resulted in significantly lower flows in this reach during late summer and early fall.

Flows should be preserved in Eagle Creek to help keep temperatures cold. The natural stream flow should be reserved at levels that would not warm the confluence. No modeling has been done to determine minimum stream flows that would preserve current cold temperatures.

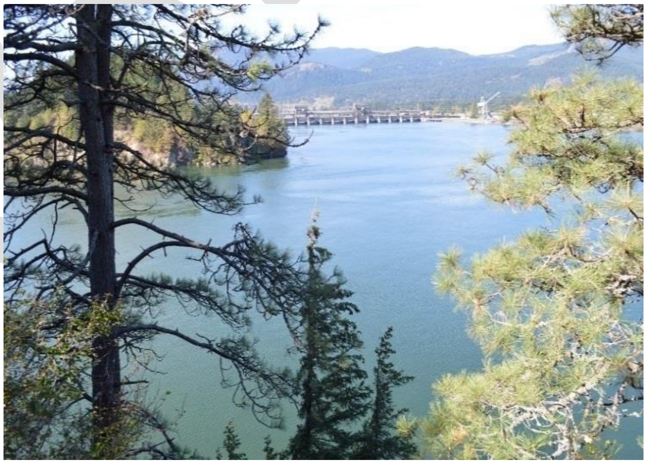


Photo 7-24 Eagle Creek looking out to Columbia River, August 2016

Ongoing Activities in the Eagle Creek Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

Protected as part of the Mark O. Hatfield Wilderness, Eagle Creek is a good quality CWR that needs to be protected and restored in areas where the September 2017 fires harmed or destroyed riparian vegetation. Actions to protect and enhance the Eagle Creek CWR include:

- Implement actions in the *USFS Hood River National Forest Land and Resource Management Plan* (1990) on federal forest lands, including the establishment of Riparian Reserves.
- Implement Oregon's Forest Practices Act at the mouth of Eagle Creek.
- Consider special designations, antidegradation policies, and/or narrative water quality criteria as appropriate to prevent warming of the creek above current temperatures and maintain existing flows.
- Identify impacts from 2017 Eagle Creek Fire and restore riparian vegetation on areas in the lower watershed to cool water temperature.
- Identify areas affected by the 2017 Eagle Creek Fire that have reduced hillslope and stream bank stability. Revegetate or stabilize bare soil to reduce sedimentation of the refuge.
- Evaluate impacts from Cascade Hatchery flow withdrawal and return on the lower 2-mile reach of Eagle Creek and any impacts to flow and temperature of the CWR plume.

7.8 HERMAN CREEK (RIVER MILE 147.5) – PROTECT AND ENHANCE

Photo 7-25 Herman Creek near the confluence with the Columbia River, August 2017

Refuge Volume: 169,698 m^3 (6th largest)

Average August Temperature: 12˚C

Distance to Downstream Refuge: 4.5 mi. (Eagle Creek)

Distance to Upstream Refuge: 3.5 mi (Wind River)

Cold Water Refuge Rating: Good (<16˚C)

Photo 7-26 Aerial view of Herman Creek and Herman Cove at confluence with Columbia River; yellow pin denotes upper extent of refuge

What features make Herman Creek an important cold water refuge?

Located at river mile 147.5, Herman Creek is one of eight primary CWR between Bonneville Dam and the Dalles Dam that fish use as they migrate upstream. Herman Creek is 4.8 miles upstream of the next closest refuge at Eagle Creek. Herman Creek temperatures in August average 12°C, 9°C cooler than the Columbia River. This temperature makes Herman Creek a good quality CWR (<16°C). The lower portion of Herman Creek is designated by ODEQ for salmon and trout rearing and migration with a water quality criterion of 18°C for maximum water temperatures. The maximum water temperature modeled for Herman Creek is 13.7°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower portion of Herman Creek is not on the 303(d) list for temperature impaired waters. Herman Creek and Herman Creek Cove provide 169,698 m^3 of cold water, the size of approximately 68 Olympic-sized swimming pools, and the sixth largest CWR in the Lower Columbia River. In August, the creek has an average flow of 45 cfs.

Photo 7-27 Herman Creek, August 2017

Constructed levees protect Herman Creek Cove from inflow of warmer Columbia River waters. Thermal stratification of the water in the cove provides a cool layer of water. The CWR is estimated to be primarily limited to the cove, the hatchery discharge channel, and an estimated 0.3 miles upstream on the Herman Creek mainstem. The Port of Cascade Locks has noted high levels of sediment at the mouth of Herman Creek, causing water levels to be shallower. The next available CWR is 3.5 miles upstream in the Wind River.

Introduction to the Herman Creek Watershed

The Herman Creek watershed is relatively small, covering 392 square miles. Herman Creek originates at Hicks Lake and flows steeply downhill in a due north direction for 8.5 miles before emptying into the Columbia River. Herman Creek Cove at the mouth of the tributary is an area where fish are known to congregate. Herman Creek Cove is fed by Herman Creek and the hatchery discharge channel. Waterfalls block fish passage at river mile 2.8 for coho and at river mile 3.5 for steelhead. The watershed consists almost entirely of protected U.S. Forest Service land (***Figure 7-22***), with most of the watershed protected as part of the Mark O. Hatfield Wilderness Area. Nearly the entire basin (98.5%) is forested; the small amount of developed and cultivated land is concentrated at the lower reaches of Herman Creek and along Herman Creek Cove. ODFW operates Oxbow Hatchery on Herman Creek. Waterfront property on the eastern side of Herman Cove has been pursued for light commercial and industrial development. Over the last decade, Nestle Corporation proposed a plan to bottle water from Oxbow Springs, reflecting the high quality of water from Oxbow Springs that feeds Little Herman Creek. In August 2017, the Eagle Creek fire affected areas near the Herman Creek watershed, but initial post-fire burn severity analysis conducted by the U.S. Forest Service indicated the watershed experienced only minor impacts from the fire.

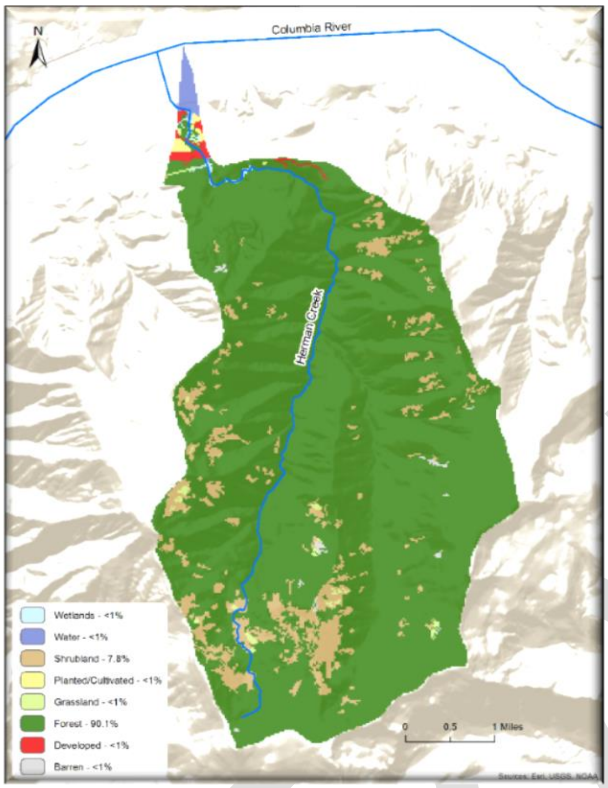


Figure 7-21 Herman Creek Land Cover

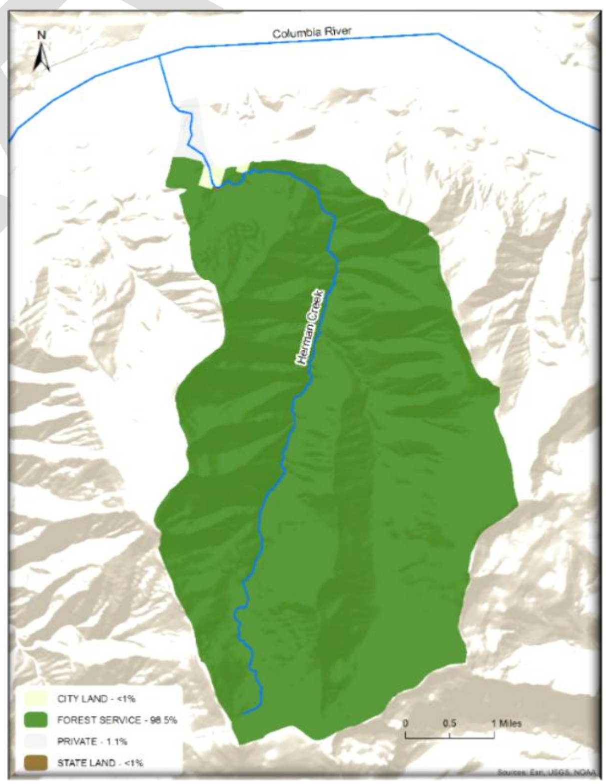


Figure 7-22 Herman Creek Ownership

Factors that Influence Temperature in the Herman Creek Watershed

Protecting and Enhancing Riparian Vegetation: The Herman Creek watershed has high levels of riparian shade throughout the well-forested watershed. This shade serves to block solar radiation and maintain cool temperatures. Riparian shade also maintains channel complexity and groundwater, which keeps water temperatures cold. ***Figure 7-23*** compares the shade difference between the potential maximum and current shade. Lower Herman Creek (from the confluence of two small tributaries with the creek to the mouth of the cove) offers potential for restoration of riparian vegetation to help improve stream cover and contribute to maintaining cool stream temperatures. This is the only area along the creek that has been developed.

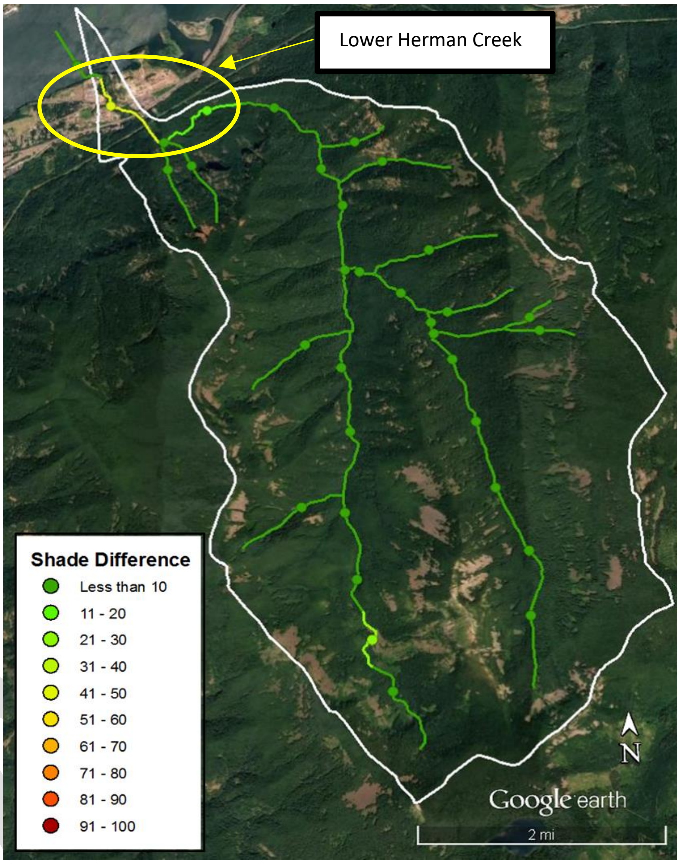


Figure 7-23 Herman Creek shade difference between potential maximum and current shade

Dams and Hydromodifications: Hydromodifications are minimal in the upper parts of the watershed. The Oxbow Hatchery operates at least two diversion dams that divert water into the hatchery before the water is returned to the creek.

Forest surveys conducted by U.S. Forest Service found little-to-no large woody debris in the lower and middle reaches due to culverts and channelization. The amount of large woody debris in the watershed did not meet the *Aquatic Conservation Strategy* goals of the Northwest Forest Plan. Placement of large woody debris in Herman Creek would help trap sediment, create pools of cold water, and improve habitat conditions for fish.

Herman Creek Cove itself is the result of levees constructed in the mid-20th century to produce a harbor for milling operations on the shore. The levees now serve to protect the cove from warmer Columbia River waters. The cove is located within the impoundment area of the downstream Bonneville Dam, and the water surface level can vary by as much as two feet in response to reservoir operations, potentially affecting access to

Photo 7-28 Oxbow Hatchery on Herman Creek, August 2017

CWR in the impoundment area if certain points become too shallow.

Table 7-4 Water Availability Analysis, Herman Creek at mouth, 5/22/18, Oregon Water Resources Department

HERMAN CR > COLUMBIA R – AT MOUTH (@ 50% exceedance)			
Month	Monthly Streamflow (cfs)		
	Natural Streamflow	Water Allocated or Reserved	% Allocated*
JUNE	77	0.13	0.1%
JULY	33	0.14	0.4%
AUGUST	20	0.13	0.6%
SEPTEMBER	18	0.11	0.6%
Top users: Domestic (71%), Irrigation (29%)			
Water net positive Year-round			
* % Allocated: [Water Allocated or Reserved]/[Natural Streamflow].This is the percentage of water either allocated or reserved for in-stream or other uses compared with the natural streamflow. Percentages over 100% indicate the water is overallocated at the mouth of the river.			
Reference: http://apps.wrd.state.or.us/apps/wars/wars_display_wa_tables/MainMenu1.aspx			

Water Use: ***Table 7-4*** shows the water availability in Herman Creek. There is minimal water use, and water availability in the summer months is close to the natural stream flow. The minimal consumptive uses of Herman Creek consist of domestic water supply by the City of Cascade Locks and for fish cultivation at Oxbow Fish Hatchery. Established in 1913, the hatchery holds water rights to withdraw 19 cfs from Oxbow Springs to the hatchery, which is discharged into Herman Creek. The hatchery has two ponds withdrawing water from Herman Creek. The upper pond withdraws water from Herman Creek but discharges back into the creek. The lower pond withdraws water from Herman Creek as well but discharges into the hatchery discharge channel. The added cold water from Oxbow Springs supplements flows in Herman Creek and Herman Creek Cove.

Climate Change: In 2040, average August temperatures in Herman Creek are expected to be 13°C compared to 22°C in the Columbia River. In 2080, August temperatures in Herman Creek are expected to rise further to 14°C compared to 23°C in the Columbia River. Therefore, Herman Creek will remain a good CWR (<16°C), even under future climate change projections. This contrasts with many other CWR in the Lower Columbia River where climate change will warm refuges to sub-optimal temperatures for salmon.

Ongoing Activities in the Herman Creek Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

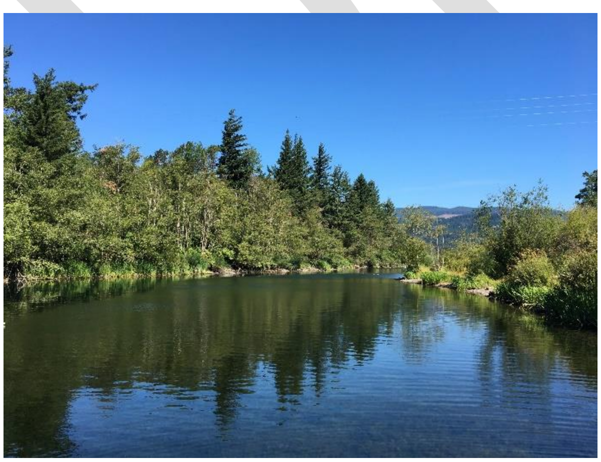


Photo 7-29 Herman Creek side channel, August 2017

Herman Creek is protected as part of the Mark O. Hatfield Wilderness. In the early 2000s, the Hood River Soil and Water Conservation District worked with USFS, Confederated Tribes of the Warm Springs, the Columbia River Inter-Tribal Fish Commission and various state agencies in Oregon to develop the *Hood River Subbasin Plan* (2004). This plan was submitted to the Northwest Power and Conservation Council to meet Endangered Species Act requirements for salmon recovery. The plan identifies several projects to improve riparian and habitat conditions in Herman Creek that align with the goals for maintaining cold water temperatures and protecting Herman Creek as a CWR. To protect steelhead and rainbow trout, the plan also identifies protecting and restoring Herman Creek from the Hatchery Diversion Dam to the falls at river miles 0.8 and 2.8. It also recommends increasing riparian vegetation and large woody debris to increase stream complexity in the middle and lower reaches.

Actions to protect and enhance Herman Creek and Herman Creek Cove include:

- Consider special designations, antidegradation policies, and/or narrative water quality criteria as appropriate to prevent warming of the creek above current temperatures and maintain existing flows.
- Protect existing riparian vegetation corridors in the watershed in accordance with federal forest protections under the Mark O. Hatfield Wilderness Area.
- Maintain existing flows in the Herman Creek watershed.
- Implement projects in the *Hood River Subbasin Plan* including increasing large woody debris in Herman Creek to decrease sedimentation at its mouth and increase riparian vegetation in lower Herman Creek from the confluence of two small tributaries of the creek to the mouth of Herman Creek Cove.
- Conduct a sediment removal feasibility study in the cove to maintain CWR volumes and access.

7.9 WIND RIVER (RIVER MILE 151) – PROTECT AND ENHANCE

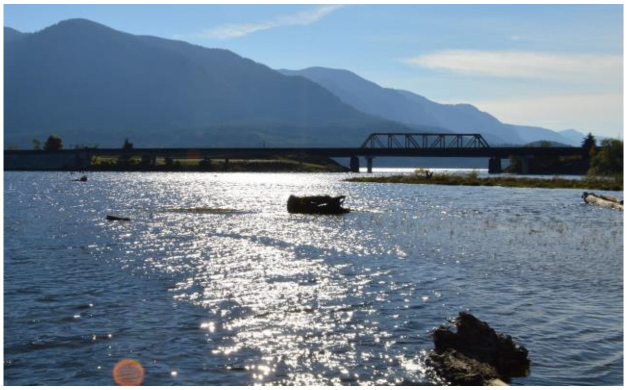


Photo 7-30 Wind River looking out to Columbia River, August 2016

Refuge Volume: 105,220 m^3 (8th largest)

Average August Temperature: 14.5°C

Distance to Downstream Refuge: 3.5 mi. (Herman Creek)

Distance to Upstream Refuge: 7.7 mi. (Little White Salmon River)

Cold Water Refuge Rating: Good (<16°C)

Photo 7-31 Aerial view of Wind River confluence with Columbia River; yellow pin denotes upstream extent

What features make the Wind River an important cold water refuge to protect and enhance?

Located approximately halfway between the Pacific Ocean and the Snake River at river mile 151 in Washington, the Wind River is one of eight primary CWR between Bonneville Dam and The Dalles Dam that fish use as they migrate upstream. The Wind River is 4.5 miles upstream of the next closest refuge in Herman Creek. Wind River temperatures in August are estimated to be 7˚C cooler than the Columbia River with average temperatures of 14.5°C, making the Wind River a good quality CWR (<16°C). Washington Department of Ecology has designated the lower portion of the Wind River as core summer salmonid habitat with a water quality criterion of 16°C for maximum water temperatures. The maximum water temperature modeled for the Wind River is 18.3°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Wind River is on the 303(d) list for temperature impaired waters.

Photo 7-32 Wind River, August 2016

The confluence of the Wind River has a large amount of sediment which has made the river mouth broader and shallower, increasing water temperatures and reducing the volume and quality of CWR habitat. This is due to a combination of anthropogenic causes, such as historical logging, and natural processes. It is estimated that migrating fish use the lower 0.8 miles of the Wind River, below Shipherd Falls, as CWR (yellow pin, ***Photo 7-31***). The Wind

River has the eighth largest CWR in the Columbia River estimated at 105,220 m^3, the size of approximately 42 Olympic-sized pools, with mean flows of 293 cfs. The next available CWR is 7.7 miles upstream in the Little White Salmon River.

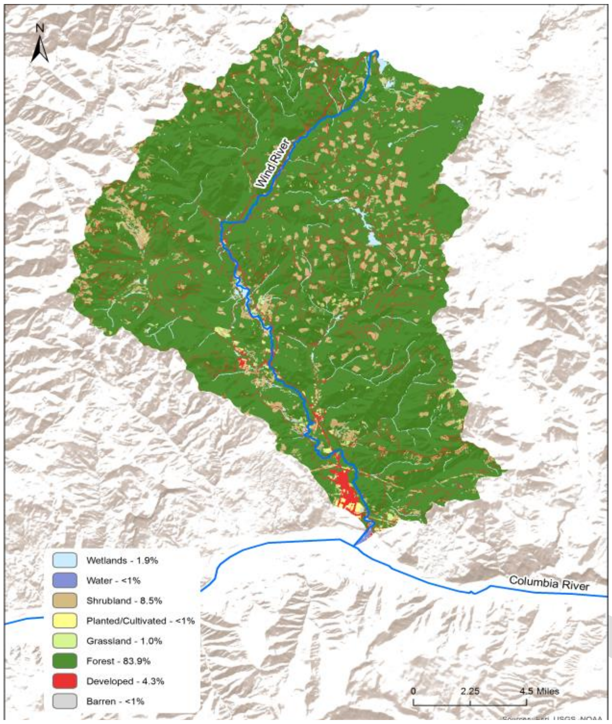


Figure 7-24 Wind River land cover

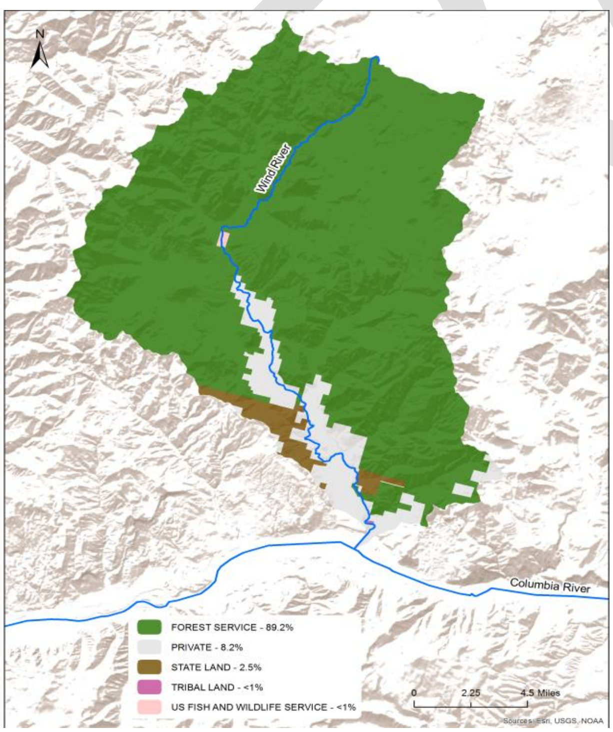


Figure 7-25 Wind River land ownership

Introduction to the Wind River Watershed

The Wind River originates in the Gifford Pinchot National Forest. Snowmelt runoff and high levels of canopy shading produce cold water temperatures. In addition, large groundwater spring inputs in upper Trout Creek, the mainstem near Carson Hatchery, and Panther Creek contribute to the River's cold temperatures. Panther Creek, the Wind's largest tributary, joins the mainstem at river mile 4.3. Panther Creek is particularly important in keeping the lower portion of the mainstem cool during the summer due to its volume and proximity to the mouth of the Wind River. The Wind River meanders and broadens at the mouth, where it passes under State Highway 14 near Home Valley, WA, before entering the Columbia River.

The Wind River watershed is mostly forested with 90% of the land owned by the USFS, with private ownership concentrated from the middle Wind River to its confluence with the Columbia River (***Figure 7-25***). The land cover near the mouth of the Wind River is primarily developed and de-forested (***Figure 7-24***) and has the greatest impact upon temperature and complexity of the CWR at the mouth of the Wind River.

Factors that Influence Temperature in the Wind River Watershed

Protecting and Enhancing Riparian Vegetation: The Wind River watershed has high levels of riparian shade throughout most of the watershed, especially in the upper well forested tributaries. These are on federal, state, and private lands that are governed by the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* and Washington's Forest Practice Rules. This shade serves to block solar radiation and maintain cool stream

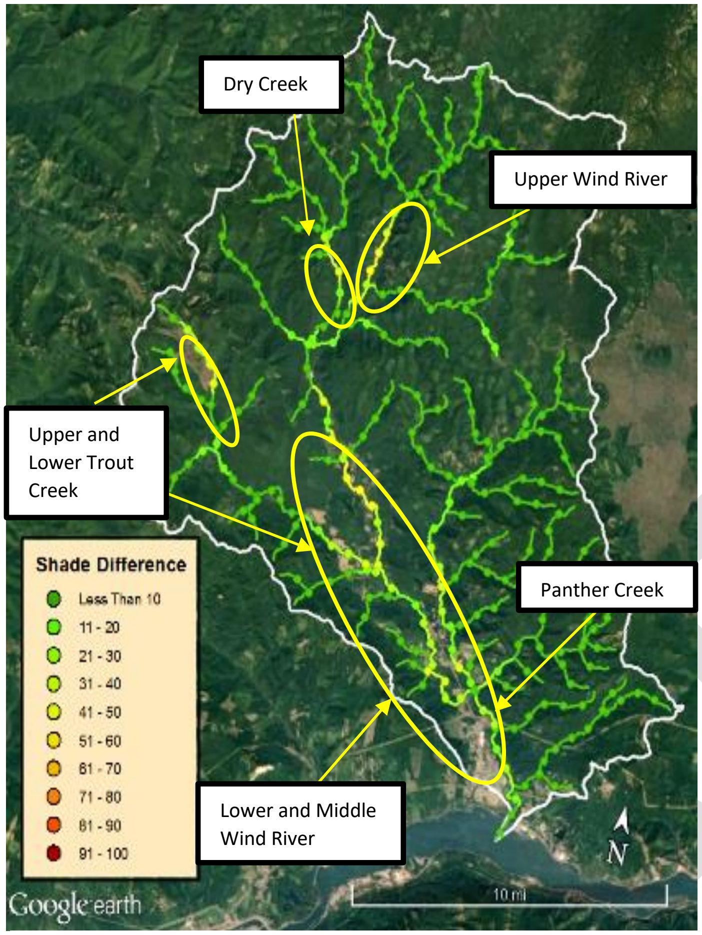


Figure 7-26 Wind River shade difference between potential maximum shade and current shade

temperatures. However, there are several reaches that have been degraded and have potential for increased shade. ***Figure 7-26*** compares the shade difference between the potential maximum and current shade. Most of the watershed is at or near the maximum vegetation for shading (dark and medium green). The areas with potential to increase riparian shade are the Wind River mainstem, Upper and Lower Trout Creek, Dry Creek (yellow and light green areas), and Panther Creek. Increasing riparian vegetation above the confluence is important because cooling water temperatures upstream will transfer downstream.

Water quality modeling in Washington Department of Ecology's *Wind River Watershed Temperature TMDL* (2001) predicted that maximum potential

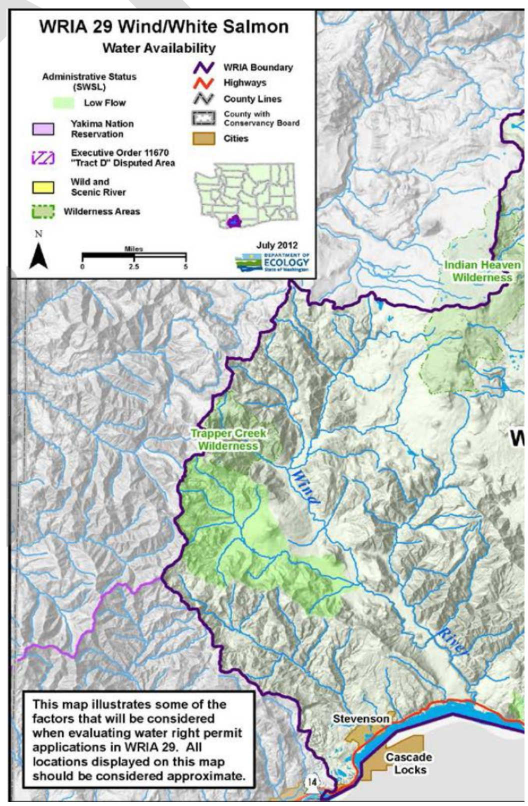


Figure 7-27 Wind River Basin – Water rights and availability, Washington Department of Ecology

vegetation could decrease water temperatures at the mouth from 18˚C to 14˚C under average flow conditions.

Dams and Hydromodifications: There are no dams in the Wind River watershed. Hemlock Dam on Trout Creek, located two miles upstream from the tributary's confluence with the Wind River, was removed in 2009. Since then, there have been significant improvements in habitat complexity in the former reach. Fish population data to date suggest a trend in increased adult and juvenile steelhead populations in Trout Creek relative to the rest of the watershed.

Water Use: ***Figure 7-27*** shows the water rights and availability in the Wind River Watershed (WRIA 29). Water rights are heavily allocated for agricultural uses. Low flows exist in the Upper and Lower Trout Creek and lower and middle Wind River. Most of the water in the Wind River Basin is allocated. While there is no instream flow rule (water rights to protect fish), there is no water set aside in reserves for future use. Trout Creek is designated a surface water source limitation area that restricts new uses. Because water use is high and supply is limited, more water use may reduce the CWR plume volume and increase temperatures in the CWR.

Climate Change: In 2040, average August temperatures in the Wind River are predicted to be 16°C compared to 22°C in the Columbia River. In 2080, August temperatures in the Wind River are expected to rise further to 17°C compared to 23°C in the Columbia River. Therefore, the Wind River will change from being a good CWR (<16°C) to an average CWR (16-18°C), unless restoration actions such as increased riparian vegetation offset increasing water temperatures. The Wind River is still expected to be more than 6°C cooler than temperatures in the Columbia River in the summer, even under climate change projections.

Photo 7-33 Wind River looking downstream to confluence, August 2017

Ongoing Activities in the Wind River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

Photo 7-34 Wind River at confluence, August 2017

Over the last several decades, groups such as the USGS, USFS, WDFW, Underwood Conservation District, and the Lower Columbia Fish Recovery Board, among others, have identified and prioritized reach-scale watershed projects. Recent plans include the *Wind River Habitat Restoration Strategy* (2017) and the *Watershed Condition Framework: FY2016 Watershed Restoration Action Plan (2015),* both of which provide detailed actions and priority areas on which to focus. These plans were submitted to the Lower Columbia Fish Recovery Board to meet Endangered Species Act requirements for salmon recovery. Further, there currently exists a temperature TMDL, developed in 2002.

Actions in these plans align directly with actions that would benefit CWR. These include a recently-completed project on the Wind River confluence to move the boat ramp and parking area to the southeast corner of the mouth, and to convert the current boat ramp and parking area to multi-threaded side channels and vegetated islands to increase complexity. Other projects include bank stabilization projects and revegetation, which would reduce erosion and sediment at the Wind River confluence and cool waters.

Actions to protect and enhance the Wind River CWR include:

- Implement actions in the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* on federal forest lands, including the establishment of Riparian Reserves.
- Implement Washington's Forest Practice Rules on state and private forest lands on the middle and lower Wind River.
- Implement actions in the mainstem Wind River, Panther Creek, and Upper and Lower Trout Creek noted in the *Wind River Habitat Restoration Strategy* and *Wind River Temperature TMDL*.
- Continue to reduce sedimentation and increase habitat complexity through bank stabilization and re-vegetation in areas upstream of the confluence and within the confluence.
- Conduct a sediment removal feasibility study at the mouth.
- Consider additional SWSLs and instream flow rules, given current limited stream flows.

7.10 LITTLE WHITE SALMON RIVER (RIVER MILE 158.7) – PROTECT AND ENHANCE

Refuge Volume: 1,101,126 m³ (2nd largest)

Average August Temperature: 13.3°C

Distance to Downstream Refuge: 7.7 mi. (Wind River)

Distance to Upstream Refuge: 6.3 mi. (White Salmon River)

Cold Water Refuge Rating: Good (<16°C)

Photo 7-35 Little White Salmon upstream view of lower hatchery intake

Photo 7-36 Aerial view of the Little White Salmon cold water refuge; yellow pin denotes the upper boundary of the refuge

What features make the Little White Salmon River an important cold water refuge to protect and enhance?

The Little White Salmon River is located at river mile 159 and is one of eight primary CWR between Bonneville Dam and The Dalles Dam that fish use to migrate upstream. The Little White Salmon River flows into Drano Lake before entering the Columbia River and is 7.7 miles upstream of the next closest refuge in Wind River. The mean August temperature of the Little White Salmon River is 13°C, almost 8°C cooler than the mainstem Columbia River in August, making the Little White Salmon River a good quality refuge (<16˚C). The lower portion of the Little White Salmon is designated for core summer salmonid habitat by the Washington Department of Ecology with a water quality criterion of 16°C for maximum water temperatures. The maximum water temperature modeled for the Little White Salmon is 15.6°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Little White Salmon River is not on the 303(d) list for temperature impaired waters.

Photo 7-37 The confluence of the Little White Salmon River via Drano Lake flowing into the Columbia River

The cooler water in the thermal refuge is primarily near the inlet of the Little White Salmon River into Drano Lake (~10°C–18°C), and at the bottom of Drano Lake (16°C–21°C), and migrating salmon are estimated to use up to 1.3 miles upstream as a refuge. Drano Lake makes the Little White Salmon River confluence the second largest CWR along the Columbia River, with a total volume of 1,101,126 m^3, approximately 450 Olympic-sized swimming pools. The Little White Salmon River has a modest summer stream flow of 88 cfs. Fish leaving the Little While Salmon will travel 6.3 miles upriver before encountering the White Salmon River, the next CWR.

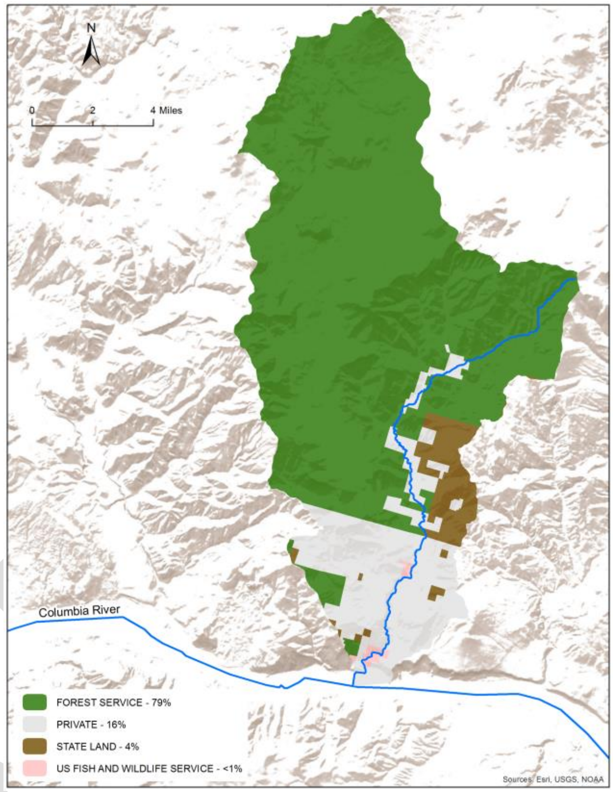


Figure 7-28 Little White Salmon River Basin land ownership

Introduction to the Little White Salmon River Watershed

The Little White Salmon River provides snow-fed water from its headwaters east of the Cascade crest to the confluence plume. The Gifford Pinchot National Forest makes up roughly 79% of the Little White Salmon River basin (***Figure 7-28***). The National Forest protects the watershed from urban and industrial development. The riparian forest buffers shade the snow- and groundwater-fed streams, keeping them cool as they flow toward the Columbia River. However, a legacy of timber harvesting has left lasting habitat impacts on the sub-basin in the form of stream-side clear cuts and roads.

State and private lands in the Little White Salmon River sub-basin are generally undeveloped. Less than 1% of the sub-basin is used for traditional agriculture (***Figure 7-29***). Only 4% of the sub-basin is developed land and is concentrated near the confluence, where most private lands are found. Timber management in Gifford Pinchot National Forest is the dominant land use (***Figure 7-28***, ***Figure 7-29***). The Gifford Pinchot National Forest prevents major urban development from occurring throughout the sub-basin. Current protections and land uses will likely continue under existing legal designations and zoning laws. The quality refuge habitat of Drano Lake makes it a popular fishing destination.

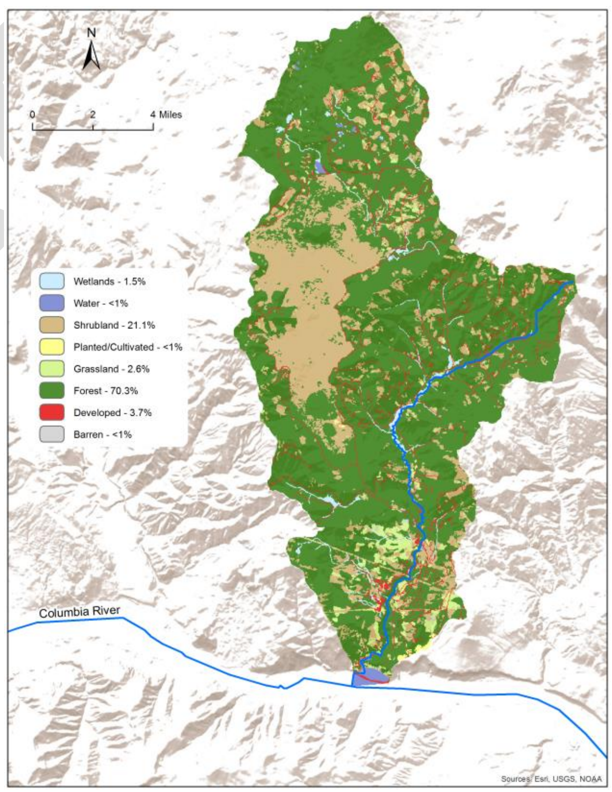


Figure 7-29 Little White Salmon River Basin land cover

Factors that Influence Temperature in the Little White Salmon River Watershed

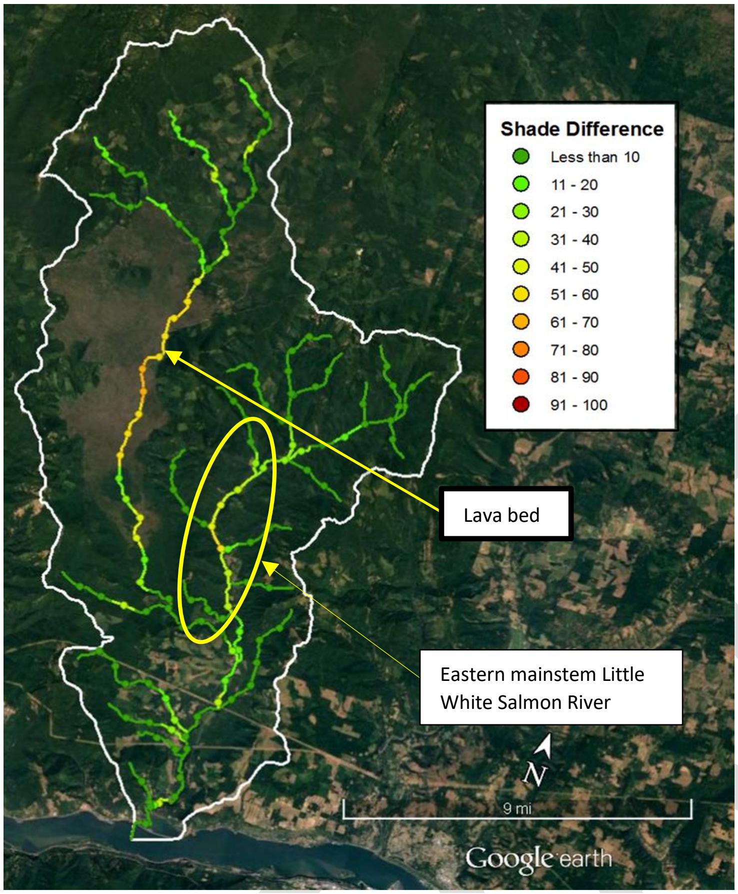


Figure 7-30 Difference between potential stream shade conditions and current stream shade

Protecting and Enhancing Riparian Vegetation: The Little White Salmon River watershed has high levels of riparian shade to maintain cool river temperatures, except for a few areas. Federal, state, and private lands are governed by the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* and Washington's Forest Practice Rules. ***Figure 7-30*** compares the shade difference between the potential maximum and current shade. Note the figure displays the greatest potential shade difference is located within a lava bed, where riparian vegetation is not feasible. The eastern mainstem of the river has the greatest potential for restoration. Although stream shade potential difference is small, restoring riparian shade in this reach could still have a positive impact on mainstream temperatures. Overall, the Little White Salmon River is well shaded with riparian buffers. The *Gifford Pinchot Forest Land and Resource Management Plan* requires wide buffers which protect water quality from timber harvest practices by reducing the effects of erosion and sedimentation.

Hydromodifications: The natural hydrology of the Little White Salmon River confluence was altered by the construction of Bonneville Dam. Backwater from Bonneville Dam and the dike that supports Highway 7 spurred the formation of Drano Lake. Drano Lake backwater inundated roughly one mile of spawning habitat at the lower Little White Salmon River and Columbia River confluence. Historically, the Little White Salmon River provided primary spawning habitat for salmonids up to river mile 2 where Spirit Falls serves as a natural fish barrier. Although inundation led to significant spawning habitat loss, Chinook and steelhead can use the cool water of Drano Lake and the lower reach of the Little White Salmon River as CWR during their migration up the Columbia River.

Photo 7-38 Bonneville Dam downstream of the Little White Salmon River confluence

The Little White Salmon River has a unique geological feature, Big Lava Bed, that covers 16,000 acres in the upper western sub-basin. Lava Creek descends into the lava bed, then reappears downstream, cooling the river as the stream flows underground. This geological feature is one of the reasons the Little White Salmon River provides such cold water to the confluence at Drano Lake.

Photo 7-39 Drano Lake

Water Use: The Little White Salmon River is located within the Wind-White Salmon Water Resource Inventory Area 29. In the greater White Salmon River and Wind River basins, most available water rights are claimed. The Washington Department of Ecology's Water Resource Explorer indicates that many water diversions exist along the river. However, the effect of water withdrawal in the Little White Salmon River basin is unclear. There is a need for more hydrology, flow, and water use data to determine the risk and protection needs in the sub-basin. Maintaining water flows is important to keeping high CWR volume and cold water temperatures in the summer.

Climate Change: In 2040, average August temperatures in the Little White Salmon River are predicted to be 15°C compared to 22°C in the Columbia River. In 2080, August temperatures in the Little White Salmon River are expected to rise further to 16°C compared to 23°C in the Columbia River. Therefore, the Little White Salmon River will change from being a good CWR (<16°C) to an average CWR (16-18°C), unless restoration actions such as increased riparian vegetation offset increasing water temperatures. The Little White Salmon River is still expected to be more than 7°C cooler than temperatures in the Columbia River in the summer, even under climate change projections.

Photo 7-40 View of the lower Little White Salmon River above Drano Lake

Ongoing Activities in the Little White Salmon River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

Sub-basin management plans for the Little White Salmon River were developed by the Northwest Power and Conservation Council and the Lower Columbia Fish Recovery Board, with contributions from Tribal entities (Columbia River Inter-Tribal Fish Commission, and the Yakama Nation) and Washington Department of Ecology and WDFW. Plans include *Klickitat Lead Entity Region Salmon Recovery Strategy* (2013), *Lower Columbia Salmon Recovery and Fish and Wildlife Plan, Little White Salmon* (2004), *Gifford Pinchot National Forest Land and Resource Management Plan* (1990), among others. Restoration efforts in the Little White Salmon River basin should also benefit habitat and thermal refuge for salmonid species. Historically, due to natural barriers at Spirit Falls, there was limited use of the upper Little White Salmon River

Basin by salmonids. Additionally, upon creation of the Bonneville Dam, backwater inundated the original habitat at the Little White Salmon River and Columbia River confluences. Due to the natural and altered hydrological regime, the restoration potential of the Little White Salmon River confluence is limited. The *Lower Columbia Salmon Recovery and Fish and Wildlife Plan* for the Little White River identified the lower and middle mainstem as priority areas to improve habitat connectivity, forest practices related to sediment, riparian vegetation, and floodplain function. The Columbia Land Trust is preserving lands along the 19-mile stretch of the Little White Salmon River under the *Klickitat and Little White Salmon Project*. However, the current implementation status of the sub-basin restoration activities is unknown.

Protecting current land-use designations and restoring riparian habitat in the basin will maintain and enhance its importance as refuge habitat for migrating salmonid species. Recommended actions to protect and enhance the Little White Salmon River CWR include:

- Implement actions in the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* on federal forest lands, including the establishment of Riparian Reserves.
- Implement Washington's Forest Practice Rules on state and private forest lands on the middle and lower Little White Salmon River.
- Implement actions related to improving habitat in the lower mainstem of the Little White Salmon River noted in the *Lower Columbia Salmon Recovery and Fish and Wildlife Plan.*
- Consider special designations, antidegradation policies, and/or narrative water quality criteria as appropriate to prevent warming above current temperatures and maintain existing flows.

7.11 WHITE SALMON RIVER (RIVER MILE 165) – PROTECT AND ENHANCE

Photo 7-41 Upstream view of the White Salmon River

Refuge Volume: 153,529 m^3 (7^{th} largest)

Average August Temperature: 15.7°C

Distance to Downstream Refuge: 6.3 mi. (Little White Salmon River)

Distance to Upstream Refuge: 1 mi. (Hood River)

Cold Water Refuge Rating: Good (<16°C)

Photo 7-42 Aerial view of the White Salmon River cold water refuge; yellow pin denotes upstream extent

What features make the White Salmon River an important Cold Water Refuge to protect and enhance?

Located at river mile 165, the White Salmon River is one of eight primary CWR between Bonneville Dam and The Dalles Dam that fish use to migrate upstream. The White Salmon River is 6.3 miles upstream of the next closest refuge at the Little White Salmon River. Average water temperatures in the White Salmon River in August are roughly 15.7°C, 5.5°C cooler than the Columbia River. This feature makes the White Salmon River a good CWR (<16°C). The Washington Department of Ecology designates the lower portion of the White Salmon River for core summer salmonid habitat and has assigned a water quality criterion of 16°C for maximum water temperatures. The maximum water temperature modeled for the White Salmon is 19.6°C (1993-2011) (Appendix 12.18). However, based on actual maximum temperature readings, the lower White Salmon River is not on the 303(d) list for temperature impaired waters (excluding the confluence water influenced by the Columbia River, which is currently listed as impaired).

Photo 7-43 Upstream of the White Salmon River confluence with the Columbia River

Migrating Chinook and steelhead have been observed using the river as a refuge an estimated 1.3 miles upstream, where there is a natural barrier of river rapids (yellow pin, ***Photo 7-42***). The cold water plume has a volume of roughly 153,529 m^3, the equivalent of 39 Olympic-sized swimming pools, and mean flows of 715 cfs, making the White Salmon River confluence the seventh largest CWR identified on the Lower Columbia River. The next available CWR is one mile upstream in the Hood River.

Introduction to the White Salmon River Watershed

With headwaters in the Gifford Pinchot National Forest, the White Salmon River watershed drains glaciers on the southwest flank of Mount Adams. The mainstem flows south for 44 miles before emptying into the Columbia River directly across from the City of Hood River, Oregon. Portions of the mainstem are designated as Wild and Scenic, and the river is a popular destination for commercial and recreational activities including fishing, kayaking, and rafting. Major tributaries include Trout Lake, Buck Creek, Mill Creek, Dry Creek, Gilmer Creek, and Rattlesnake Creek. The river remains cool throughout the year due to snowmelt runoff and contributions from groundwater. Groundwater recharge provides an estimated 200 cfs or more of baseflow to the river throughout the year, with the largest contribution occurring between June and September when precipitation averages below 2 inches per month.

The Gifford Pinchot National Forest, managed by the U.S. Forest Service, protects the slopes of Mount Adams in the upper watershed and composes nearly half of the basin's land area (48%). The lower portion of the basin is a mix of private and state-owned land (***Figure 7-31***). The White Salmon River basin is largely forested (66%), with developed (5%) and cultivated lands (3%) along riparian areas south of Trout Lake to the Columbia River confluence. The lower three miles of the river are part of the Columbia River Gorge National Scenic Area. Road networks exist throughout the watershed, but the most heavily developed areas surround the unincorporated community of Underwood near the river's confluence with the mainstem Columbia River.

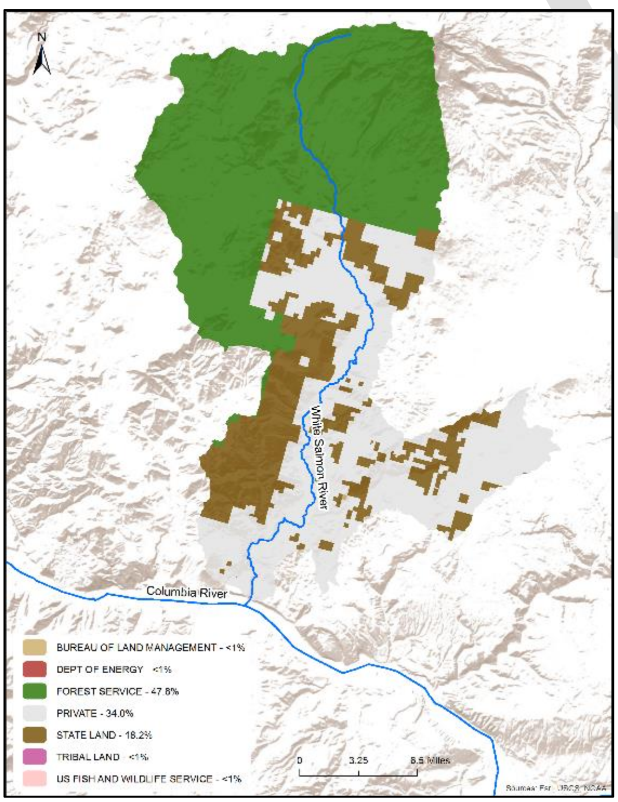


Figure 7-31 White Salmon River Basin land ownership

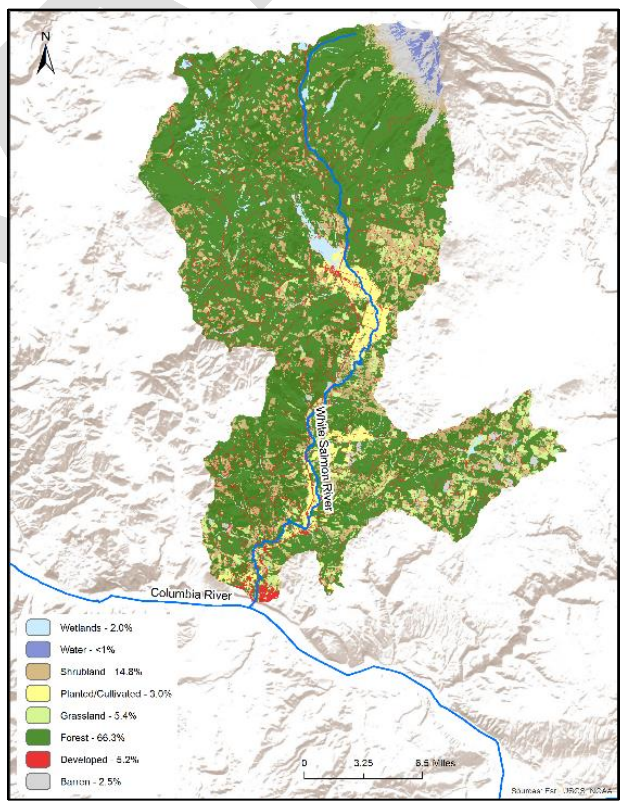


Figure 7-32 White Salmon River Basin land use

Photo 7-44 White Salmon River confluence before and after the removal of the Condit Dam; USGS, U.S. Department of Interior, 2015

Factors that Influence Temperature in the White Salmon River Watershed

Protecting and Enhancing Riparian Vegetation: The White Salmon River watershed has high levels of riparian shade throughout most of the watershed, except for some areas mostly on private land. Federal lands are governed by the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* (1990) in the upper watershed. State and private forestlands in the middle and lower watershed are governed by Washington's Forest Practice Rules. ***Figure 7-33*** highlights the difference between current and potential maximum shade. The yellow, orange and red river segments reflect the areas with the most potential for enhancing riparian cover (***Figure 7-33***). There is some potential for enhancing riparian vegetation along the mainstem segments and tributaries around and south of Trout Lake Creek confluence, and in segments of the Rattlesnake Creek tributary in the southeastern area of the sub-basin. The largest potential for restoration is in the eastern portion of the mid-basin where there is a high proportion of agricultural or pasture land (circled, ***Figure 7-33***).

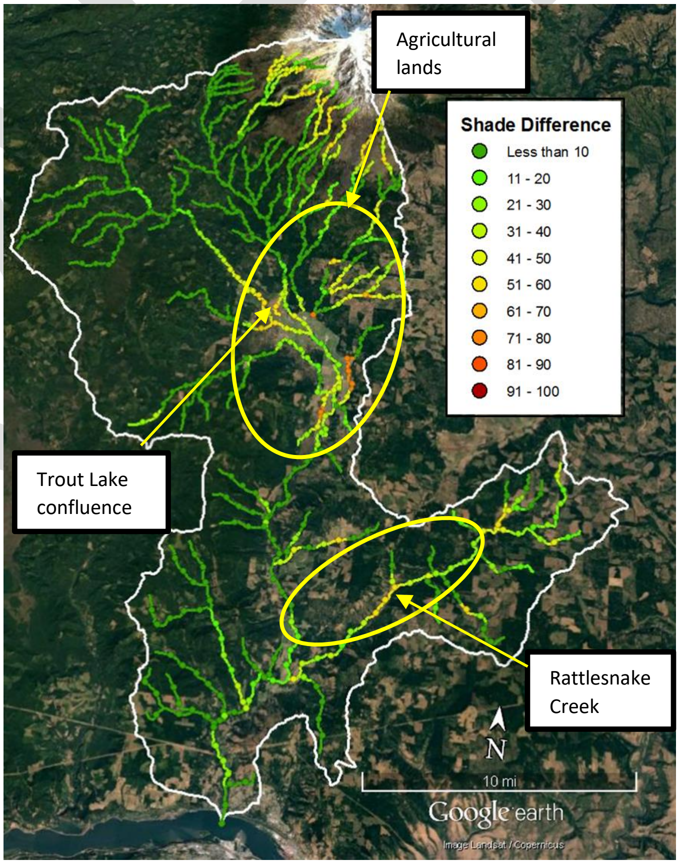


Figure 7-33 White Salmon River Shade Difference Potential Maximum and Current Shade

Hydromodifications: Currently, there are no dams in the White Salmon River. The most significant hydromodifications on the White Salmon River relate to the operation and removal (2012) of Condit Dam. The initial breaching of the dam was rapid, resulting in short-term damage to salmonid and aquatic life, as large amounts of sediment were flushed downstream. Conditions have since settled and improved. While the dam removal effectively increased potential habitat for migrating salmon, much of the built-up sediment previously trapped behind the dam settled downstream near the Columbia River confluence. This resulted in the formation of a new beach line at the confluence, reducing the average depth and total volume of

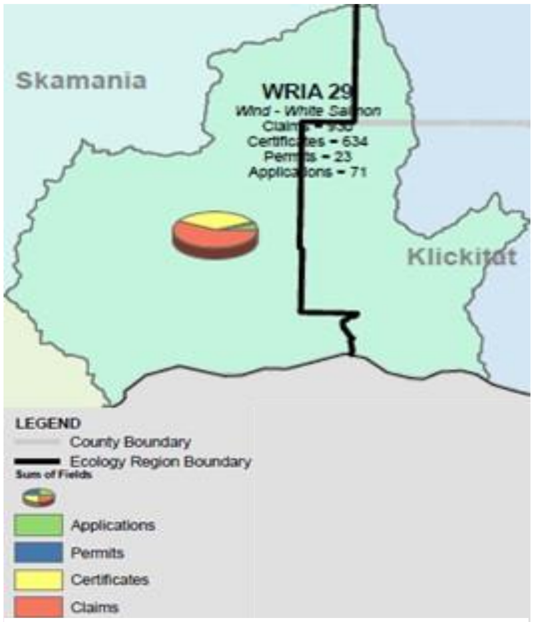


Photo 7-45 Water rights in the Wind-White Salmon, December 2016 (Washington Department of Ecology)

the CWR used by salmon at the confluence plume. Confluence conditions are dynamic; gravel banks continue to shift and expand in the lower stem during high flow events.

Water Use: Water rights for the White Salmon River basin are managed under Washington WRIA 29, which includes the Wind River and Little White Salmon River to the west. Water rights in WRIA 29 operate under a prior-appropriation system. There are no existing instream flow rules (water rights to protect fish). There is a need for more water use data to determine the risk and protection needs in the sub-basin. Maintaining water flows is important to keeping high CWR volume and cold water temperatures in the summer.

Climate Change: In 2040, average August temperatures in the White Salmon River are predicted to be 17°C compared to 23°C in the Columbia River. In 2080, August temperatures in the White Salmon River are expected to rise further to 18°C compared to 24°C in the Columbia River. Therefore, the White Salmon River is expected to be an average CWR (16-18°C), even under climate change projections. The White Salmon River is still expected to be more than 6°C cooler than temperatures in the Columbia River in the summer.

Ongoing Activities in the White Salmon River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

The removal of Condit Dam resulted in an increase in restoration projects and initiatives to protect returning salmonid populations and their spawning and rearing habitats. Along with the Wild and Scenic River land designation protections, these initiatives align with many of the same best practices to protect and enhance the confluence as a CWR. Goals for Wild and Scenic Rivers include keeping rivers “largely primitive and [their] shorelines undisturbed,” which aligns with CWR goals of reduced sedimentation and the preservation of riparian vegetation.

The site of the Underwood Indian Village was inundated by sediments after the removal of the Condit Dam, limiting fishery access for Columbia River Treaty Tribes. Yakama Nation Fisheries conducted a restoration project in 2018 to manage the sediment delta that formed at the White Salmon/Columbia River confluence. This project included dredging the navigation channel and using the dredge material to build islands to minimize shallow nearshore habitats near the confluence and restore habitat for juvenile salmonids.

Photo 7-46 West side of the confluence with the Columbia River with emerging sediment delta

Recommended actions to protect and enhance the White Salmon River CWR include:

- Implement actions in the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* on federal forest lands, including the establishment of Riparian Reserves in the upper White Salmon River.
- Implement Washington's Forest Practice Rules on state and private forest lands on the middle and lower White Salmon River.
- Restore riparian vegetation around Trout Lake, tributary headwaters below the Mount Adams tree line, and Rattlesnake Creek.
- Assess sediment impacts to CWR from Condit Dam removal and continue conducting sediment removal feasibility studies at the mouth of the White Salmon River to preserve CWR volume and temperatures.

7.12 HOOD RIVER (RIVER MILE 166) – PROTECT AND ENHANCE

Photo 7-47 Hood River

Refuge Volume: 28,000 m^3 (11th largest)

Average August Temperature: 15.5°C

Distance to Downstream Refuge: 1 mi. (White Salmon River)

Distance to Upstream Refuge: 11 mi. (Klickitat River)

Cold Water Refuge Rating: Average (16-18°C)

Photo 7-48 Aerial view of Hood River at the confluence with Columbia River; yellow pin denotes upstream extent

What features make the Hood River an important cold water refuge to protect and enhance?

Located at river mile 166 of the Columbia River, the Hood River is approximately halfway between the Bonneville Dam and Dalles Dam. It is located one mile upstream from the White Salmon River, the next downstream refuge. Hood River temperatures in August average 15.5°C, 6°C cooler than the Columbia River. This classifies the Hood River a good CWR (<16°C). However, the large sand bar at the confluence, channelization in the lower Hood River, and relatively low depth (~0.8 meters) in the summer may present barriers to salmon using the Hood River as a refuge. Additionally, a fish monitoring station near the mouth of the Hood River detected few out-of-basin steelhead (10-15 annually) migrating upstream of the station between 2010-2015. For that reason, only the mouth of the Hood River is included as a CWR (***Photo 7-48***).

Photo 7-49 Middle Fork of the Hood River

The lower portion of the Hood River is designated by ODEQ as core cold water habitat with an assigned water quality criterion of 16°C for maximum water temperatures. The maximum water temperature modeled for the Hood River is 19.1°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Hood River is on the 303(d) list for temperature impaired waters. The Hood River is the eleventh largest CWR in the Lower Columbia River with a cold water plume volume of 28,000 m^3, or 11 Olympic-sized swimming pools, and mean flows of 374 cfs. The next available CWR is 11 miles upstream in the Klickitat River.

Introduction to the Hood River Watershed

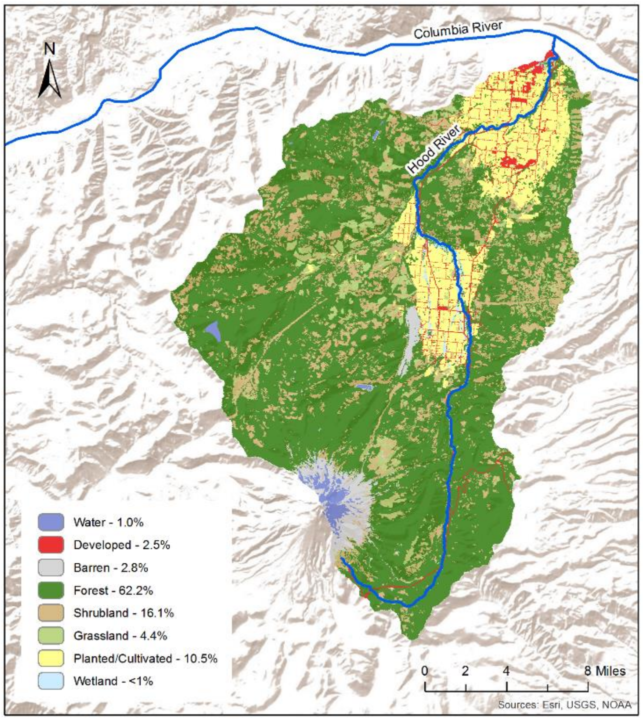


Figure 7-34 Hood River land cover

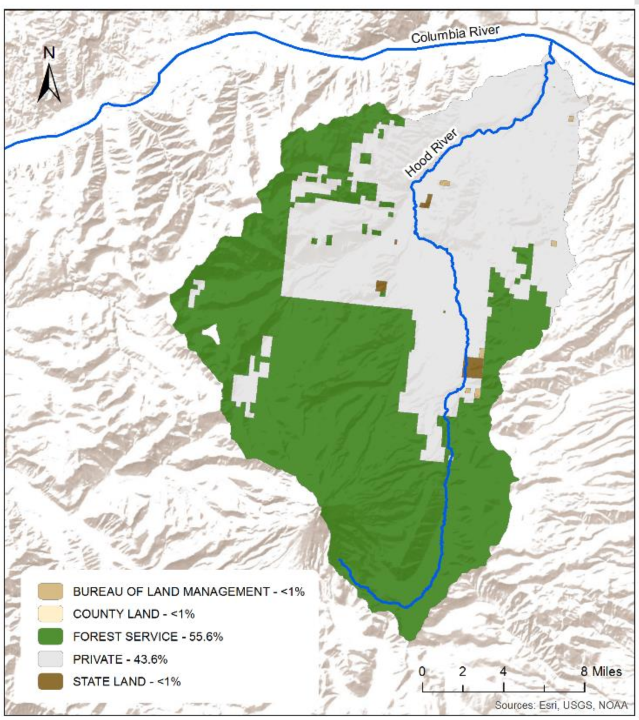


Figure 7-35 Hood River land ownership

The Hood River watershed drains the snow-laden eastern flank of Mount Hood and the land to the north of the volcano. Three major tributaries, the East, West, and Middle Forks, cascade down from the mountainous headwaters. The longest tributary, East Fork, drains Mount Hood Meadows ski and snowboard resort and flows east and then north, collecting Dog River and the Middle Fork before meeting the West Fork near the small unincorporated community of Dee, Oregon, approximately 11 miles south of the City of Hood River, the only significant urban development in the basin. Above this confluence, the East Fork is considered the mainstem Hood River.

Protected as part of the Mount Hood National Forest, much of the upper basin retains natural land cover, contributing to high levels of riparian shading. Approximately 60% of the basin is forested; shrubland (16%) is found in fragments throughout the watershed and cultivated crops (11%) predominate on flat topography south of Hood River and surrounding Dee. USFS owns and manages 56% of the watershed, with the remaining 44% privately owned (***Figure 7-35***). The City of Hood River, located at the confluence of the Hood and Columbia Rivers, has the largest population in the watershed. In the past, the Hood River delta and lowlands were flooded during the construction of Bonneville Dam. Currently, the mouth of Hood River is channelized.

Factors that Influence Temperature in the Hood River Watershed

Protecting and Enhancing Riparian Vegetation*:* Although much of the Hood River watershed is well shaded to maintain

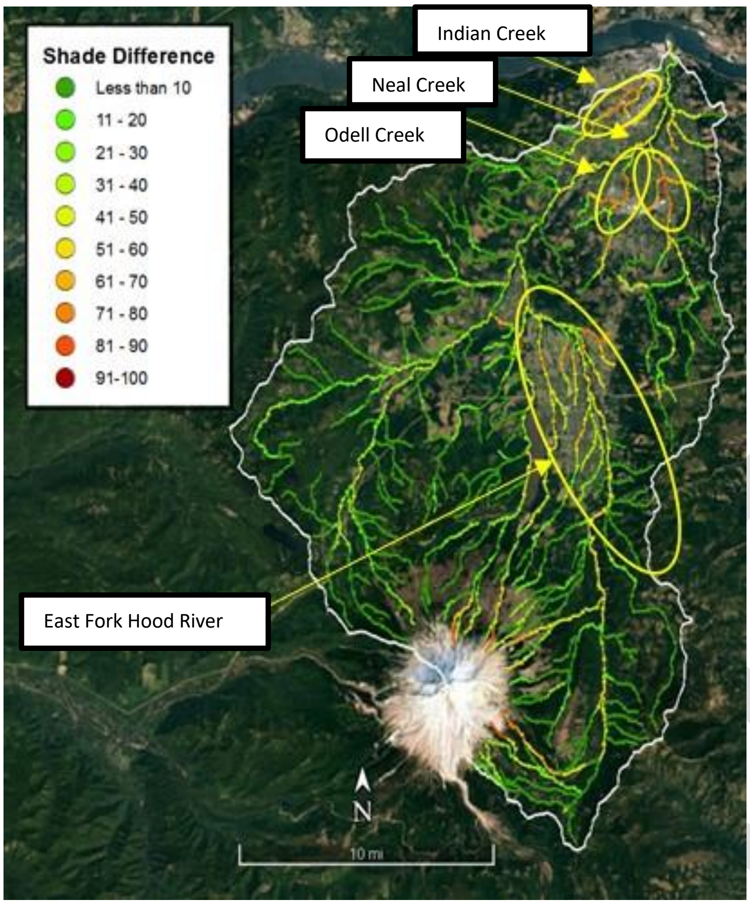


Figure 7-36 Hood River shade difference between potential maximum and current shade

cool river temperatures, there are several developed river reaches that have lost much of their riparian shade. ***Figure 7-36*** displays the difference between potential maximum and current shade conditions, helping to identify reaches in the middle and lower Hood River that could be restored to provide more riparian shade where high levels of development and agriculture occurs. On average, shading from riparian conditions could be improved by 37% to cool temperatures at the confluence. Areas with the most potential for riparian shade include Indian Creek, Odell Creek, Neal Creek, and the East Fork Hood River Creek. Water quality modeling in ODEQ's *Western Hood Subbasin TMDL* (2001) predicted maximum potential vegetation and a minimum instream flow of 250 cfs from Powerdale Dam could decrease maximum water temperatures at the mouth from 18˚C to 15˚C under low flow conditions.

Dams and Hydromodifications: In the past, Powerdale Dam, located on river mile 4.5 of the Hood River, withdrew significant amounts of water that affected the water quality and quantity downstream in a 3-mile bypass reach. In 2010, the Powerdale Dam was decommissioned. Although there are no permanent flow and temperature gauges since Powerdale Dam was removed, the updated *2018 Western Hood Subbasin TMDL* projected that temperatures would decrease with increased flows of up to 500 cfs in the lower 4.5 miles of the Hood River. A small hydroelectric dam on Odell Creek was removed in 2016, which has expanded the time for resident salmonid spawning. The dam on Clear Branch, a tributary to the Middle Fork Hood River, heats temperatures downstream of the reservoir during most of the summer.

Photo 7-50 Hood River at the site of the former Powerdale Dam

Water Use: Irrigation is the dominant water use, and there are past and ongoing efforts to improve the efficiency of irrigating crops to reduce water demand, decrease agricultural runoff, and increase flow in streams. The three primary irrigation districts are: Farmer's Irrigation District (FID), Middle Fork Irrigation District (MFID), and East Fork Irrigation District (EFID). MFID operates the Clear Branch Dam for irrigation. EFID has the largest water withdrawals for irrigation. ***Figure 7-37***, from the *2006 USFS Mount Hood National Forest Aquatic Habitat Restoration Strategy*, shows the large amount of diversions throughout the basin, especially the lower Hood River. The figure also shows the now-decommissioned Powerdale Dam. In 2016, the Hood River Soil and Water Conservation District published the *Hood River Water Conservation Strategy*, a report developed with the agricultural community to evaluate different alternatives to reduce water usage. The Hood River is not overallocated during the summer months at the mouth. However, improving irrigation water efficiency will increase the water quality and quantity for resident and migratory fish in the tributaries and mouth of the Hood River.

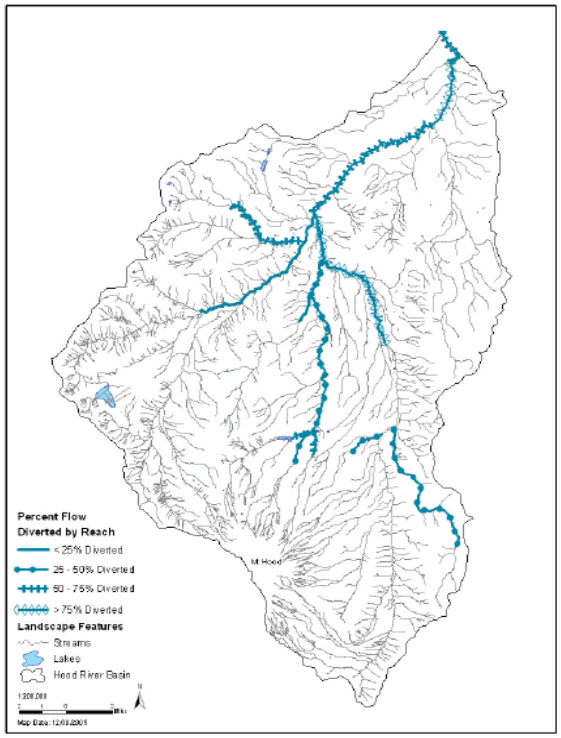


Figure 7-37 Estimated flow diversions in the Hood River Basin in 2006

Table 7-5 Water Availability Analysis, Hood River at mouth, 5/23/18, Oregon Water Resources Department

HOOD RIVER > COLUMBIA R – AT MOUTH (@ 50% exceedance)			
Month	Monthly Streamflow (cfs)		
	Natural Streamflow	Water Allocated or Reserved	% Allocated*
JUNE	1,040	319	31%
JULY	739	281	38%
AUGUST	559	239	43%
SEPTEMBER	511	168	33%
Top three users: Irrigation (67%), Domestic (17%), Agriculture (13%)			
* % Allocated: [Water Allocated or Reserved]/[Natural Streamflow]. This is the percentage of water either allocated or reserved for in-stream or other uses compared with the natural streamflow. Percentages over 100% indicate the water is overallocated at the mouth of the river.			

Reference:
https://apps.wrd.state.or.us/apps/wars/wars_display_wa_tables/display_wa_complete_report.aspx?ws_id=71480&exlevel=50&scenario_id=1

Climate Change: In 2040, August temperatures in the Hood River are projected to rise to 16°C, compared to 23°C in the Columbia River. In 2080, August temperatures in the Hood River are expected to rise to 17°C compared to 24°C in the Columbia River. Therefore, increases in Hood River temperatures are expected to keep the Hood River as an average CWR (16-18°C). Still, the Hood River is expected to be more than 7°C cooler than temperatures in the Columbia River in the summer, even under climate change projections.

Ongoing Activities in the Hood River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

The history of watershed plans with targeted actions and partnerships provide a solid foundation for protecting and improving conditions in the basin and at the confluence. In 2004, the Hood River Soil and Water Conservation District completed the *Hood River Subbasin Plan*, a comprehensive review of the watershed with prioritized actions identified by many stakeholders in the basin. In 2006, the USFS completed the *Hood River Aquatic Habitat Restoration Strategy,* which targets the lower watershed for greater riparian cover and increased flows. In 2016, the Soil and Water Conservation District released a study on water conservation and efficiency, *Hood River Water Conservation Strategy*. ODEQ updated its *Western Hood Basin TMDL* in 2018, retaining the riparian shade targets from the 2001 TMDL. Numerous other plans have been developed targeting efforts on USFS lands, more efficient water use, reduction of pesticide use and runoff, improving fish passage and habitat, among other plans. The Confederated Tribes of the Warms Springs has worked extensively in the basin with monitoring and restoration projects. Many recommendations in these plans will benefit the downstream CWR area. Increased riparian vegetation on agricultural land will reduce pesticide runoff and shade streams, helping improve water quality.

Actions to protect and enhance the Hood River CWR include:

- Implement actions in the *USFS Mount Hood National Forest Land and Resource Management Plan* and *Hood River Aquatic Habitat Restoration Strategy* on federal forests, including the establishment of Riparian Reserves.
- Improve riparian vegetation where possible in the lower reaches of the Hood River including Indian Creek, Neal Creek, Odell Creek, and the area of the decommissioned Powerdale Dam (**Photo 7-50**) as noted in the *Western Hood Basin TMDL* (2018) and *Hood River Subbasin Plan*.
- Continue implementing water efficiency projects to maintain and increase flows in the Hood River basin noted in the *Hood River Water Conservation Strategy*.
- Increase the amount of instream large woody debris to create pools of cold water and trap sediment that would otherwise reach the river mouth.
- Support education and outreach opportunities for habitat and riparian restoration on privately-owned properties in Hood River watershed plans.

7.13 KLICKITAT RIVER (RIVER MILE 177) – PROTECT AND ENHANCE

Photo 7-51 Klickitat River near the confluence with the Columbia River

Refuge Volume: 222,029 m^3 (5th largest)

Average August Temperature: 16.4°C

Distance to Downstream Refuge: 11 mi. (Hood River)

Distance to Upstream Refuge: 24 mi. (Deschutes River)

Cold Water Refuge Rating: Average (16-18°C)

Photo 7-52 Aerial view of Klickitat River confluence with Columbia River; yellow pin denotes upstream extent.

What features make the Klickitat River an important cold water refuge to protect and enhance?

The Klickitat River watershed is located at river mile 177 of the Columbia River, approximately halfway between the Pacific Ocean and Snake River. It is one of the first tributaries migrating salmon encounter east of the Cascades. The Klickitat River is eleven miles upstream of the CWR in the Hood River. Average August temperatures in the Klickitat River are estimated to be 16.4°C, approximately 5°C cooler than the Columbia River. This classifies the Klickitat River as an average CWR (16-18°C). With mean flows of 851 cfs and lower temperatures relative to the Columbia River, migrating fish use the confluence and approximately 1.8 miles of stream in the Klickitat River as a CWR (yellow pin, ***Photo 7-52***).

Photo 7-53 Klickitat River, upstream of confluence

The lower portion of the Klickitat River is designated as core summer salmonid habitat by Washington Department of Ecology, which assigns a water quality criterion of 16°C for maximum water temperatures. The maximum water temperature modeled for the Klickitat River is 20.5°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Klickitat River is on the 303(d) list for temperature impaired waters. The Klickitat River has the fifth largest CWR in the

Columbia River with a flow of 851 cfs and volume estimated at 222,029 m^3, the size of approximately 89 Olympic-sized pools. The next available CWR is 24 miles upstream in the Deschutes River.

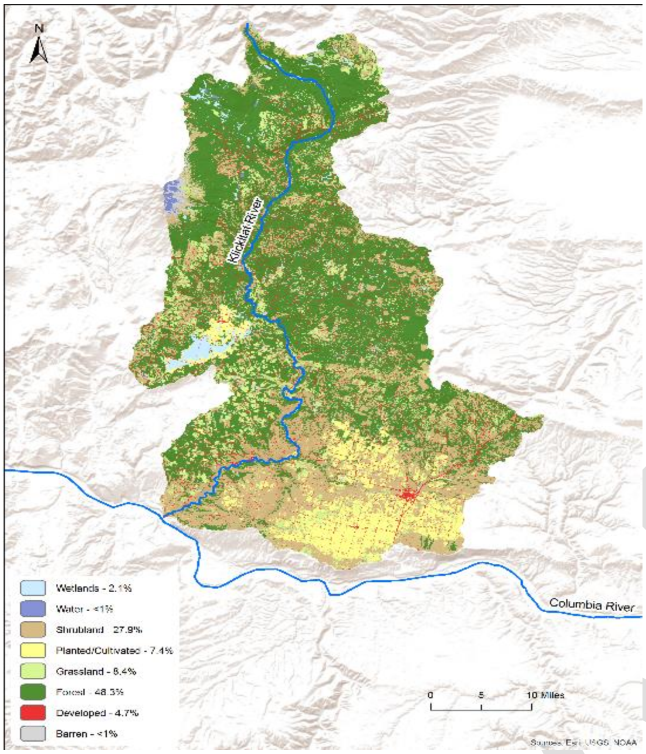
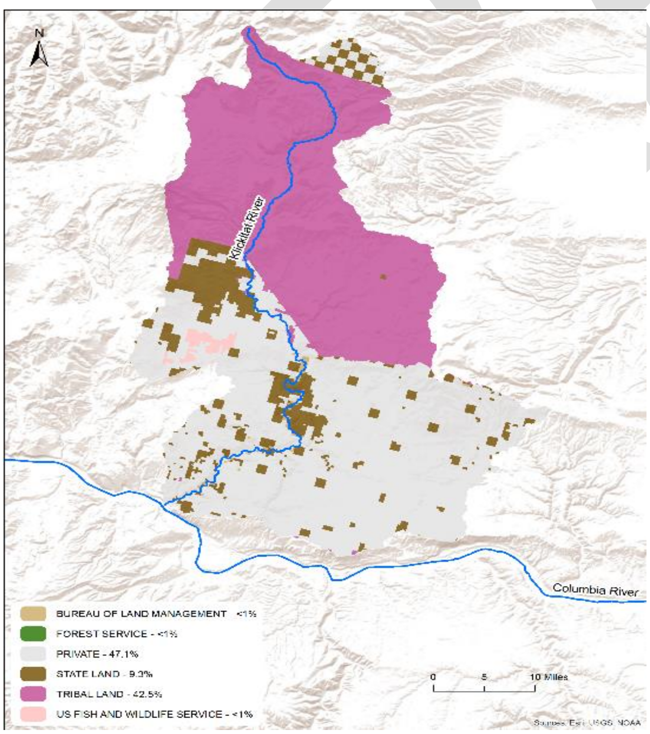


Figure 7-38 Klickitat River land cover



Introduction to the Klickitat River Watershed

The Klickitat River originates from snowmelt off Gilbert Peak on the Yakama Indian Reservation. The River flows south, collecting water from the eastern slopes of Mount Adams and drains the Lincoln Plateau before cutting through steep canyons on its way to the Columbia River near Lyle, WA. Snowmelt runoff and the underlying volcanic basalt rock that create groundwater pools recharge the Klickitat River and provide cool water to the river throughout the summer.

The Klickitat River watershed is semi-arid with a mix of land uses. Forested lands cover nearly half the basin (48%), primarily in the upper watershed (***Figure 7-38***). Shrubland (28%) is found in fragments throughout the basin and along the lower mainstem Klickitat River. Grasslands are interspersed throughout the upper basin (8%) and planted/cultivated lands (7%) surround the small community of Centerville, WA, the patch of developed land (5%) in the southeast of the basin.

The Yakama Nation owns and manages most of the upper watershed (42%), including the largest extent of forested areas. The lower half of the watershed is mostly privately owned (47%) with a mix of forested, shrubland, planted/cultivated and developed areas. State lands make up 9% of the watershed; the Bureau of Land Management, U.S. Forest Service, and U.S. Fish and Wildlife Service each manage small (<1%) portions of the basin (***Figure 7-39***). The lower 10 miles of the Klickitat River have federal Wild and Scenic designations.

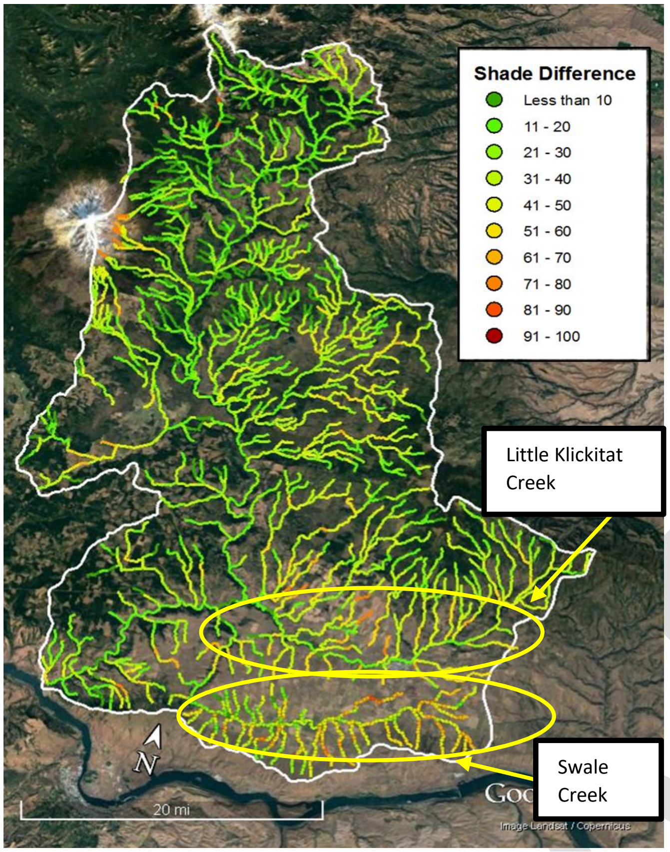


Figure 7-40 Klickitat River shade difference between potential maximum and current shade

Factors that Influence Temperature in the Klickitat River Watershed

Protecting and Enhancing Riparian Vegetation:

Tributaries to the Klickitat River have relatively higher shade levels than the mainstem Klickitat River. The lower and mid-mainstem are limited in how much shade is possible because of canyons along the Klickitat River. ***Figure 7-40*** compares the shade differences between the potential maximum and current shade. Swale Creek is impacted by floodplain filling, grading, and bank armoring associated with railroad construction, which has increased erosion and decreased the amount of vegetation. Little Klickitat Creek has the most potential for increased shading in the Klickitat Watershed. Water quality modeling in Washington Department of Ecology's *Little Klickitat River Watershed Temperature TMDL* (2002) concluded that potential maximum vegetation and reduced width to depth ratios could decrease temperatures at the mouth from 23ºC to 21.5ºC under average flow conditions.

Dams and Hydromodifications: There are no dams in the mainstem Klickitat River. Lyle Falls is a series of five cascades at river mile 2.2. The creation of the Bonneville Pool altered the conditions at the mouth. Before the construction of the Bonneville Dam, historic aerial photos of the confluence show a multi-thread channel with expansive cottonwood. Today, the Klickitat River is confined to a straight, simplified channel that lacks the complexity of the natural confluence.

Water Use: Water availability is limited in the watershed, both in the upper Klickitat River, within the Yakama Nation tribal boundaries, and in the lower portions. WDFW has recommended a surface water source limitation for Swale Creek and in certain areas of the Little Klickitat

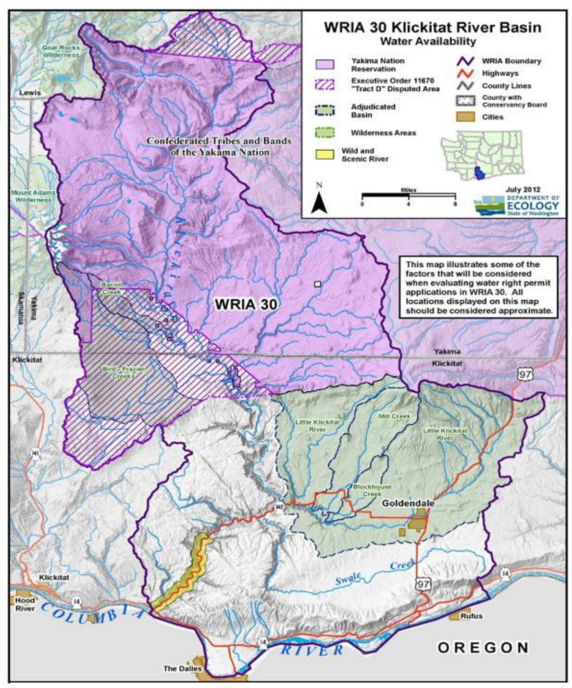


Figure 7-41 Water Availability in WRIA 30 (Washington Department of Ecology, Revised 2012)

Figure 7-39 Klickitat ownership

watershed, where Washington Department of Ecology can condition or deny new water rights permits. ***Figure 7-41*** shows that Little Klickitat, Mill Creek, and Blockhouse Creek Basins are "adjudicated basins," which means that water right disputes may be resolved in courts. Basins with past adjudications typically indicate that little water is available for new permits. Because water use is high and supply is limited, more water use may reduce the CWR plume volume and increase temperatures in the CWR.

Photo 7-54 Klickitat River sandbar into Columbia River

Climate Change: In 2040, average August temperatures in the Klickitat River are predicted to be 18°C compared to 23°C in the Columbia River. In 2080, August temperatures in the Klickitat River are expected to rise further to 19°C compared to 24°C in the Columbia River. Therefore, the Klickitat River will change from being an average CWR (16-18°C) to a marginal CWR (>18°C), unless restoration actions such as riparian vegetation and increased water flows offset increasing water temperatures. The Klickitat River is still expected to be more than 5°C cooler than temperatures in the Columbia River in the summer, even under climate change projections.

Photo 7-55 Basalt in Klickitat River

Ongoing Activities in the Klickitat River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

The Klickitat River watershed has been studied by many entities in the watershed including the Yakama Nation, Klickitat County, and City of Goldendale among others. Recent projects and plans include Yakama Nation's Klickitat Watershed Enhancement Project (KWEP), *Klickitat Lead Entity Salmon Recovery Strategy* (2013), *Klickitat Basin (WRIA 30) Watershed Management Plan (2005),* and *Little Klickitat Watershed Temperature TMDL (2002).* The focus of these projects is to restore stream processes and improve habitat conditions and water quality. Completed projects include restoration of fish passage, meadows restoration, forest road management, floodplain reconnection, wood replenishment, and side channel reconnection. These actions in the lower watershed directly align with and benefit CWR. Studies in the Little Klickitat River also identified locations and actions to reduce river temperatures and restore thermal complexity that align with the goal of reducing temperatures in the lower Klickitat River.

Actions to protect and enhance the Klickitat River CWR include:

- Implement projects identified in the *Klickitat Lead Entity Salmon Recovery Strategy* and through the KWEP that restore stream processes, including increasing large woody debris, channel complexity, and floodplain reconnection on the mainstem Klickitat River, Little Klickitat River, and Swale Creek.

- Implement *Little Klickitat River Temperature TMD*L targets for increased riparian shade in the Little Klickitat River.
- Support education and outreach about grant and tax benefits for habitat and riparian restoration on privately-owned properties.
- Maintain or increase flows in the Klickitat River through flow conservation, trading, and minimum instream flows in the summer.

7.14 FIFTEENMILE CREEK (RIVER MILE 188.9) – RESTORE

Refuge Volume: N/A

Average August Temperature: 19.15°C

Distance to Downstream Refuge: 11.9 mi. (Klickitat River)

Distance to Upstream Refuge: 12.1 mi (Deschutes River)

Cold Water Refuge Rating: Marginal (>18°C)

Photo 7-56 Looking downstream from the confluence with The Dalles Dam in the background

Photo 7-57 Flow of Fifteenmile Creek into the Columbia River in August, 2017; the water pooled below is backwater from the Columbia River

What features make Fifteenmile Creek a potential cold water refuge to restore?

Entering the Columbia River at river mile 188.9 immediately downstream of The Dalles dam, Fifteenmile Creek is in the drier, eastern end of the Columbia River Gorge. It is located twelve miles upstream of the CWR in the Klickitat River. Average August water temperatures in Fifteenmile Creek are estimated to be 19°C, approximately 2°C colder than the Columbia River. Currently, an annual August stream flow of 4 cfs and relatively high stream temperatures prevent Fifteenmile Creek from serving as a CWR for migrating salmonids. If restored, Fifteenmile Creek could serve as an additional refuge for migrating salmonids.

The lower portion of Fifteenmile Creek is designated for salmon and trout rearing and migration with an assigned water quality criterion of 18°C for maximum water temperatures. The maximum water temperature modeled for Fifteenmile Creek is 26°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower portion of Fifteenmile Creek is on the 303(d) list for temperature impaired waters. Migrating salmonids will need to travel twelve miles upstream before reaching the next CWR in the Deschutes River.

Introduction to the Fifteenmile Creek Watershed

Fifteenmile Creek originates from Senecal Spring in the eastern foothills of Mount Hood. The creek flows in a northeast direction before making a large bend to the west prior to joining the mainstem Columbia River. Its primary tributaries include Eightmile Creek, Dry Creek, Fivemile Creek, Ramsey Creek, and Larch Creek.

The Fifteenmile Creek basin is dominated by private landownership (>85%). A portion of the Mount Hood National Forest managed by the U.S. Forest Service, the only federally-owned land in the watershed, covers the forested slopes of the upper basin, and composes 15% of the basin (***Figure 7-42***). Although U.S. Forest Service land is harvested for timber, land management practices are designed to minimize impacts on streams by conserving headwaters and associated riparian buffers.

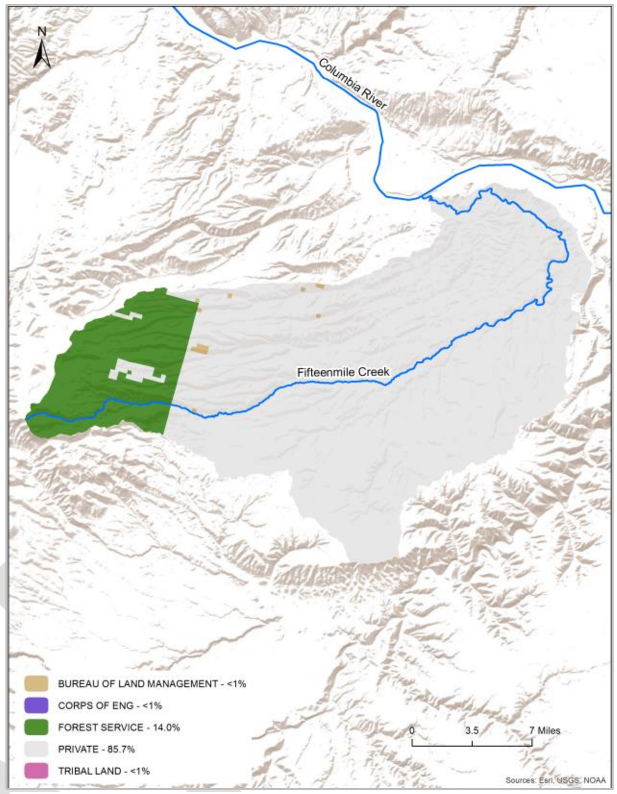


Figure 7-42 Fifteenmile Creek land ownership

Forested lands (18%) are confined to the higher elevation slopes and narrow riparian corridors bordering tributaries in the upper watershed (***Figure 7-43***). Fragmented patches of grasslands (6%) can be found in the upper basin as well. In the lower, flatter, and more arid portions of the basin, shrubland (47%) and cultivated crops (27%) predominate. The watershed's only developed land (3%) is concentrated near the creek mouth in the eastern end of The Dalles, and the small community of Dufur in the middle of the watershed.

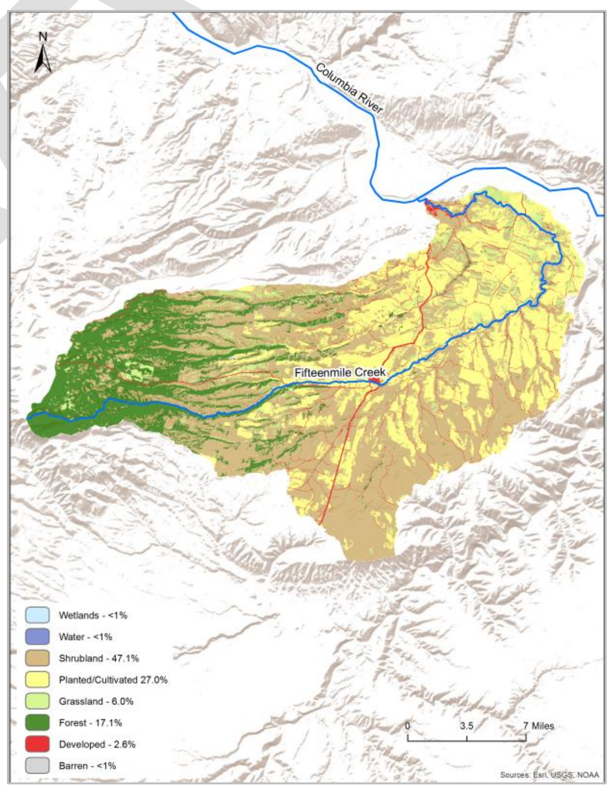


Figure 7-43 Fifteenmile Creek land use

Fed by snow-melt runoff and groundwater contributions, Fifteenmile Creek could potentially deliver cold water down to the confluence, providing additional CWR for migrating salmonids with continued water quantity and riparian habitat restoration. However, agriculture is vital to the local economy, valued at roughly $22 million per year. Agricultural land types include orchards, vineyards, and pasture. Primary agricultural products include wheat, cattle, and cherries.

Factors that Influence Temperature in the Fifteenmile Creek Watershed

Riparian Vegetation: There is a substantial area for additional riparian vegetation restoration in the lower watershed along the tributary streams and creeks on the mainstem (***Figure 7-44***). The lower watershed was widely denuded for use as agricultural land.

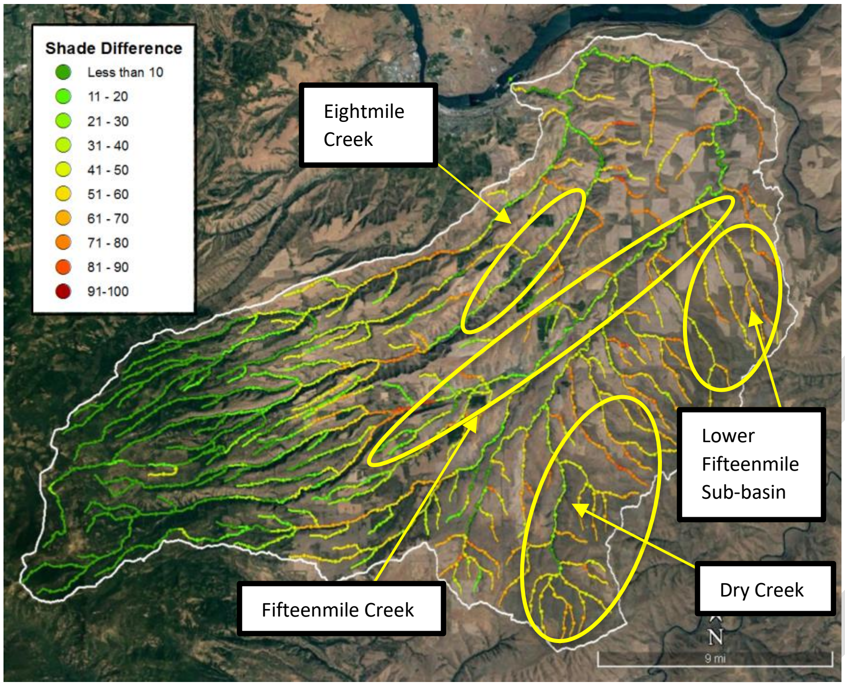


Figure 7-44 Fifteenmile Creek shade difference between potential maximum and current shade

Figure 7-44 highlights areas with potential for substantial restoration on the finger tributaries that contribute to the mainstem. These areas include the Lower Fifteenmile sub-basin, Eightmile Creek, and small tributaries of Dry Creek. There is also potential for restoration on the southeast portion of the sub-basin. The conversion of riparian areas to agricultural lands has resulted in the removal of tall grasses and small trees. Water quality modeling in ODEQ's *Middle Columbia-Hood (Miles Creek) Subbasin TMDL* (2008) predicted that maximum potential vegetation and increased flows could decrease water temperatures at the mouth from 25˚C to 18˚C under low flow conditions, a significant decrease.

Hydromodifications: Stream channels have been modified via road crossings, diversions, dikes, ditches, etc. to develop farm land, accommodate roads, and protect infrastructure. There are significant surface water alterations to accommodate agricultural irrigation in the sub-basin. These modifications alter the hydrologic connectivity to the floodplain and intensify streambank erosion. Historical modeling indicates that flows were likely naturally low in the basin, so additional water withdrawals and diversions during the critical summer period can have an exacerbated effect. There are several aquifers in the Fifteenmile Creek drainage basin. Groundwater levels are declining despite the unknowns regarding groundwater-surface water connections; however, these decline rates can be reduced by improving well construction and reducing pumping through cooperative agreements.

Water Use: Consumptive water right use is highest in July. Watermasters are limited in their regulatory authority, as they can only regulate based on priority date of the water right and not to protect water quality or species. Of the ten 6th order watersheds within the basin, three - Middle Eightmile, Lower Fifteenmile and Upper Eightmile - have 75% or more of the instream flow diverted. Information to better understand the connective hydrodynamics between authorized underground pumping and Fifteenmile Creek will inform the sustainability of pumping and may impact Watermasters' decision making.

Climate Change: Like the other cold water tributaries, average August temperatures in Fifteenmile Creek are predicted to increase approximately 1.5°C in 2040 for a temperature of 20.7°C, compared to 23°C in the Columbia River. In 2080, August temperatures in Fifteenmile Creek are expected to rise further to 21.7°C, compared to almost 24°C in the Columbia River.

Ongoing Activities in the Fifteenmile Creek Watershed and Recommended Actions to Restore the Cold Water Refuge

The *2004 Fifteenmile Subbasin Plan* developed by Northwest Power and Conservation Council and the Fifteenmile Coordinating Group (including, but not limited to, Confederated Tribes of the Warm Springs, Wasco County Soil & Water Conservation District, NOAA Fisheries, ODEQ, Oregon DFW, Oregon Water Resources Department, and USFS) highlights the need for continued collaboration and the importance of cross-leveraging funds to implement best management practices and priority restoration projects. The plan promotes a restoration philosophy to protect the remaining high quality, productive aquatic habitats in the basin, which is typically the most effective and least costly approach long-term. Other plans include USFS's *Fifteen Mile Creek Basin Aquatic Habitat Restoration Strategy* (2010), *Middle Columbia-Hood (Miles Creek) TMDL,* and Wasco Soil and Conservation District's *Fifteenmile Watershed Assessment* (2003). ODFW's *Conservation and Recovery Plan for Oregon Steelhead Populations in the Middle Columbia River Steelhead Distinct Population Segment* (2010) and NOAA's *Middle Columbia Steelhead ESA Recovery Plan* (2009) identified Fifteenmile Creek as important for steelhead populations. As a result, many agencies have focused restoration actions in Fifteenmile Creek. Because of these efforts and the potential to reduce temperatures, EPA selected Fifteenmile Creek as a CWR to be restored.

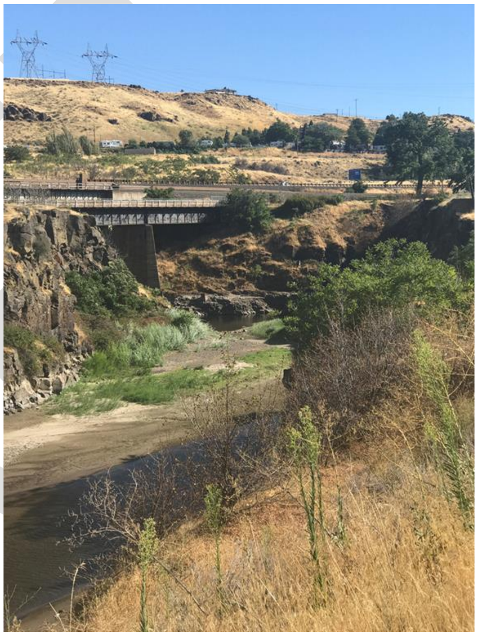


Photo 7-58 Looking upstream from the confluence toward the Fifteenmile Creek flow

Restoring habitat along riparian areas and restoring flow are both important to reestablish Fifteenmile Creek as a CWR. Groundwater decline can be reduced through improved well construction and reduction of pumping through cooperative agreements. The Wasco County Conservation District manages a program, Fifteenmile Action to Stabilize Temperature (FAST), based on predictive modeling that alerts local irrigators to alter their practices when temperatures are lethal for salmon and steelhead at two or more sites for two or more days. It also provides financial compensation to irrigators for their participation in the program. The Fifteenmile Watershed Council spurred work to install new gauges to improve the understanding of flow throughout the basin and increase the ability to regulate water withdrawals.

Actions to further restore Fifteenmile Creek include:

- Implement actions in the *USFS Mount Hood National Forest Land and Resource Management Plan* on federal forest lands, including the establishment of Riparian Reserves.
- Continue partnerships to purchase or lease in-stream water rights during critical periods for salmonids.
- Promote and fund irrigation efficiency activities and equipment to adaptively manage practices when temperatures rise.

- Improve channel connectivity with floodplains and side-channels as noted in salmon recovery plans and the *Fifteen Mile Creek Basin Aquatic Habitat Restoration Strategy*.
- Maintain the riparian restoration work done in previous years as noted in the *Fifteen Mile Creek Basin Aquatic Habitat Restoration Strategy* and *Middle Columbia-Hood (Miles Creek) TMDL*.
- Encourage private landowners to enter riparian buffer programs. Fund fencing projects for pasture lands near riparian areas to minimize the impacts of grazing.
- Refer to the Subbasin Plan to focus restoration efforts on priority areas identified by the locally-vetted prioritization method.

7.15 DESCHUTES RIVER (RIVER MILE 201) – PROTECT AND ENHANCE

Refuge Volume: 880,124 m^3 (3rd largest)

Average August Temperature: 19.2°C

Distance to Downstream Refuge: 24 mi. (Klickitat River)

Distance to Upstream Refuge: No Upstream Refuge before Snake River

Cold Water Refuge Rating: Marginal (>18°C)

Photo 7-59 Deschutes River, directly upstream of its confluence with the Columbia River

Photo 7-60 Aerial view of the Deschutes River; the upstream boundary of the cold water refuge is demarcated by the yellow pin

What features make the Deschutes River an important cold water refuge to protect and enhance?

The Deschutes River joins the Columbia River at river mile 201, approximately 24 miles upstream of Klickitat River, the closest downstream refuge. In August, the mouth of the Deschutes River averages 19°C, typically about 2°C colder than the Columbia River in August. Because migrating salmon and steelhead are more vulnerable in temperatures above 18°C, the Deschutes confluence is a marginal quality CWR (>18°C). The lower portion of the Deschutes River is designated for salmon and trout rearing and migration by ODEQ, which assigns a water quality criterion of 18°C for maximum water temperatures. The maximum water temperature modeled for the Deschutes River is 26.9°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Deschutes River is on the 303(d) list for temperature impaired waters.

The average August volume of the CWR at the mouth of the Deschutes River is 880,124 m^3, and the average flow is 4,772 cfs. This makes the Deschutes River one of the largest CWR in the Lower Columbia River system, with a plume approximately the size of 352 Olympic-sized swimming pools. A PIT-tag receiver at the mouth of the Deschutes River and radio-tag studies

Photo 7-61 Lower Deschutes River, viewed from the west bank

have documented extensive use of the lower 3.2 miles of the river for cold water use by salmon and steelhead (yellow pin, ***Photo 7-60***). The Deschutes River is the last CWR before the confluence with the Snake River.

Introduction to the Deschutes River Watershed

Photo 7-62 Moody Rapids, approximately 1 km upstream of the confluence

The Deschutes River watershed is the second largest river drainage system in Oregon, flowing through the eastern, more arid, side of the Cascades. The Deschutes River and its tributaries are fed by large amounts of precipitation, mostly snow, coming from the Cascade Mountains. This amounts to more than 100 inches annually, while additional sources of precipitation come from the Ochoco Mountains (40 inches), and lower central areas (10 inches). The river is also heavily influenced by groundwater above Lake Billy Chinook, contributing approximately 80% of the mean annual flow entering the lake. The Deschutes River's large flow and relatively cooler water results in an observable plume of cold water at the confluence with the Columbia River. The Deschutes River has one major hydroelectric complex, the Pelton Round Butte Hydroelectric Project, which forms Lake Billy Chinook approximately 100 miles upstream of its confluence with the Columbia River.

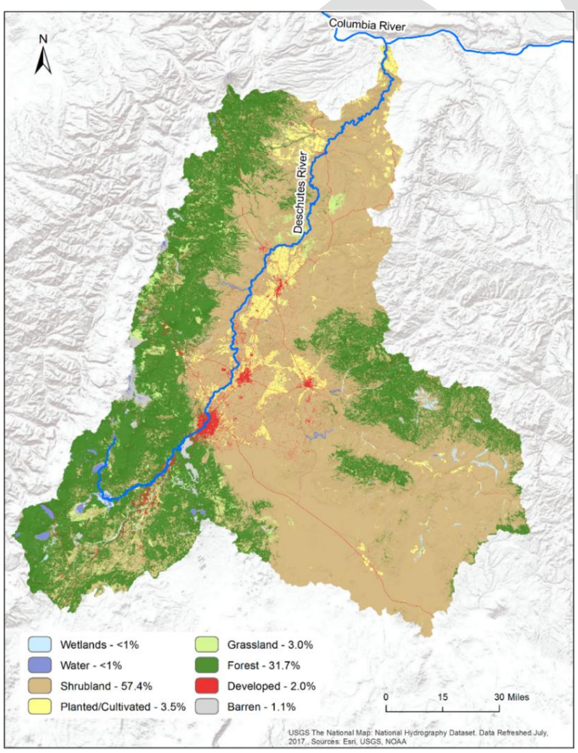


Figure 7-45 Land use in the Deschutes Basin

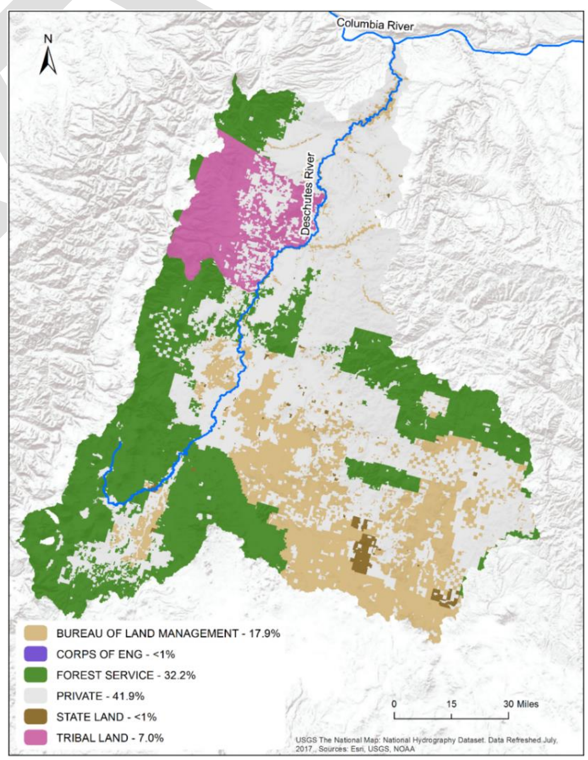


Figure 7-46 Land ownership in the Deschutes Basin

Just over half of the Deschutes River drainage area consists of shrubland (57%), in addition to moderate amounts of forested area located mostly near the headwaters (32%) (***Figure 7-45***). The top two land owners/managers in the Deschutes River drainage area are private landowners (42%) and the U.S. Forest Service (32%). Tribal land comprises 7% of land ownership. The Bureau of Land Management manages about 18% of the land in the watershed, some adjacent to the lower Deschutes River, and the majority of which is in the Crooked River watershed above the Pelton-Round Butte complex (***Figure 7-46***). In the Deschutes River watershed, degradation has occurred through livestock use, forestry and agricultural practices, invasion by western juniper, and water storage and diversions. Degradation from urbanization in the Bend, Prineville, Redmond, and Sisters areas has also occurred.

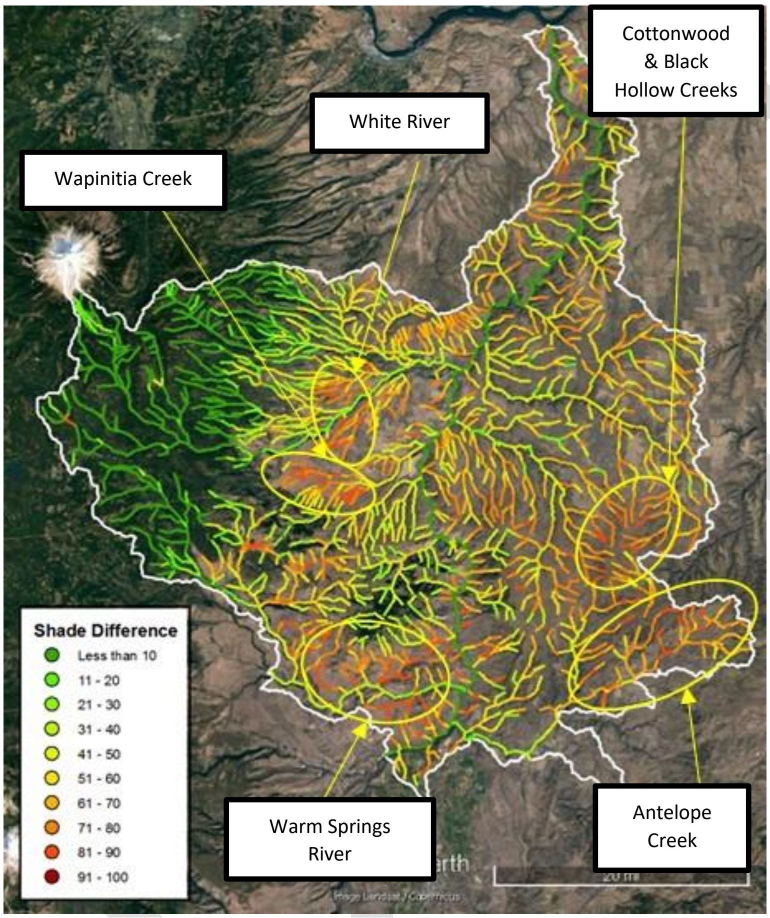


Figure 7-47 Deschutes River shade difference between potential maximum and current shade

Factors that Influence Temperature in the Deschutes River Watershed

Riparian Vegetation*:* The riparian vegetation analysis has focused on the lower part of the watershed (within a 50 mile radius of the confluence). Although the headwaters in the cascades on forest lands is currently well-shaded, a large portion of the lower basins is not well-shaded. The mainstem of the Deschutes River does not have a high potential for shade, likely due to its large width. ***Figure 7-47*** compares the shade differences between the system potential and current shade. Efforts to restore riparian vegetation would likely make the largest difference in areas with the largest shade difference. Large portions of the lower Deschutes River watershed have a semi-arid climate, and habitat restoration in these areas is likely to be slow. Most of the land in areas with the highest potential for improvement is located on privately owned or tribal lands. Thus, restoration activities will require cooperation from landowners as well as the Confederated Tribes of the Warm Springs. Revegetation in the tributaries will improve their overall health and may also have a cumulative cooling effect on the Deschutes River itself. It should be noted that these maps were developed prior to the summer 2018 fire, which burned much of the riparian vegetation in the lower 38 miles of the Deschutes River.

Dams and Hydromodifications*:* The Deschutes River, particularly the lower portion below Lake Billy Chinook to its confluence with the Columbia River, is influenced by the Pelton Round Butte Hydroelectric Project. Pelton Round Butte is composed of three dams, beginning downstream of Lake Billy Chinook: the Round Butte Dam, the Pelton Dam, and the Re-regulating Dam. Pelton Round Butte is owned jointly by Portland General Electric and the Confederated Tribes of the Warm Springs/Warm Springs Power Enterprises.

Table 7-6 Water Availability Analysis for the Deschutes River confluence with the Columbia River

DESCHUTES R > COLUMBIA R - AB MOUTH AT GAGE 14103000 (@ 50% exceedance)			
Month	Monthly Streamflow (cfs)		
	Natural Streamflow	Water Allocated or Reserved	% Allocated*
JUNE	6,600	5,670	86%
JULY	5,190	5,408	104%
AUGUST	4,780	4,813	101%
SEPTEMBER	4,800	4,997	104%
Top three users: Irrigation (87%), Municipal (8%), Storage (4%)			
Water net positive January - June			
* % Allocated: [Water Allocated or Reserved]/[Natural Streamflow].This is the percentage of water either allocated or reserved for in-stream or other uses compared with the natural streamflow. Percentages over 100% indicate the water is over-allocated at the mouth of the river.			

Reference: http://apps.wrd.state.or.us/apps/wars/wars_display_wa_tables/MainMenu1.aspx

In 2009, the building of a Selective Water Withdrawal tower above the Round Butte Dam was completed. The SWW facilities allow the temperature of downstream water releases to be regulated to more closely match the natural thermal profile, and it allows for downstream juvenile fish passage. The changed operations have increased temperatures exiting the dam in spring and early summer and cooled the temperatures in August and September. Due to the timing of the warmer spring and early summer releases, the changed operations do not appear to have increased temperatures in the lower Deschutes River during mid- to late summer when the Deschutes River is being used as a CWR for migrating salmon and steelhead. Additionally, due to the distance between the dam and the confluence and temperature attenuation, slightly cooler temperatures released at the dam in August and September from the changed operations are unlikely to have an effect on temperatures at the confluence.

Water Use: ***Table 7-6*** displays Oregon Water Resources Department data on water usage in the Deschutes River watershed. These calculations are based on flow data collected at the mouth of the Deschutes River, using the 50 percent flow exceedance value. Comparing the total uses and reserved in-stream flow with the natural streamflow, or expected flow, can indicate potential over-allocation. The Deschutes River has an in-stream flow requirement ranging from 3,500–4,000 cfs in June through September, which helps to maintain flows and cool temperatures.

However, irrigation water diversions are significant in Deschutes River. Efforts to reduce diversions and maintain higher flows in the lower Deschutes River and in tributaries to the lower Deschutes River, like Trout Creek, can serve to maintain and potentially enhance the CWR at the confluence.

Climate Change*:* Currently, the Deschutes River averages 19.2°C in August. Modeled stream temperature data from NorWeST shows that by 2040, this is predicted to increase to 20.5°C, and by 2080 to 21.6°C. Comparatively, the mainstem of the Columbia River at river mile 201 where the Deschutes River enters currently averages 21.5°C in August. At this location the Columbia River is predicted to rise to 23.0°C and 24.0°C by 2040 and 2080, respectively. While the Deschutes River is predicted to remain relatively cooler than the Columbia River by about

2.5°C, by 2040, it is likely to be above accepted temperature thresholds for migration. By 2080, it is likely to reach lethal levels for steelhead and salmon.

Ongoing Activities in the Deschutes River Watershed and Recommended Actions to Protect and Enhance the Cold Water Refuge

Photo 7-63 Confluence of the Deschutes River with the Columbia River

The Deschutes River has many active watershed groups looking to restore more favorable habitat for cold water fish. One group, the Deschutes River Conservancy, is engaged in restoring stream flow to the river. Most of their work is focused upstream of the Pelton Round Butte Hydroelectric Project where more of the water is diverted for irrigation. Their activities include water rights transfers, water rights leasing, and promotion of water conservation. The Crooked River and Upper Deschutes Watershed Councils have been actively working on riparian restoration in their respective watersheds. The Lower Deschutes Weed Control Project is an ongoing partnership with several agencies and organizations, focusing on invasive species removal in the lower 40 miles of the Deschutes River. While this may not directly impact temperatures, it is important for improving the overall health of the riparian corridor.

Along with state, tribal, and local partners, NOAA Fisheries adopted the *Middle Columbia River Steelhead Recovery Plan* in 2009. Appendix A of this plan, which is specific to Oregon and can be found on NOAA's website, provides information on the population and recovery strategies for steelhead in several sub-basins, including the Deschutes. Overall priorities for the Deschutes River include maintaining or restoring flow and restoring vegetation. The lower Deschutes River is heavily influenced by groundwater which enters the Deschutes River near Lake Billy Chinook above the Complex. This groundwater, which enters the aquifer in the high Cascades, provides a substantial amount of cold water and if degraded, has potential to jeopardize the Deschutes River CWR. Management of the Pelton Round Butte Hydroelectric Project and the SWW tower will continue to be important factors for the quality of cold water in the Deschutes River.

Actions to protect and enhance the Deschutes River CWR include:

- Protect sources of groundwater from degradation in quality and quantity. Specifically, continue the existing protections and mitigation requirements in place for new groundwater withdrawals above Pelton Round Butte.
- Support partnerships to purchase or lease in-stream water rights during critical periods to benefit salmonids.
- Restore riparian vegetation in the tributaries with the highest shade potential (Antelope Creek, Buck Hollow Creek, Cottonwood Creek, Wapinitia Creek, Warm Springs River, White River) as noted in the *Middle Columbia River Steelhead Recovery Plan*.
- Evaluate how SWW tower management scenarios could reduce the lower Deschutes River water temperatures in late August and September when CWR use is highest.

7.16 UMATILLA RIVER (RIVER MILE 284.7) - RESTORE

Refuge Volume: 46,299 m^3 (9th largest)

Average August Temperature: 20.8°C

Distance to Downstream Refuge: 83.7 mi. (Deschutes River)

Distance to Upstream Refuge: N/A

Cold Water Refuge Rating: Marginal (>18°C)

Photo 7-64 Photo of the Umatilla River confluence with the Columbia River

Figure 7-48 Aerial view of the confluence of the Umatilla and Columbia Rivers; yellow pin denotes upstream extent of refuge

What features make the Umatilla River a potential cold water refuge to restore?

The Umatilla River confluence with the Columbia River is located at river mile 284.7, just downstream of McNary Dam. The Deschutes River is the nearest downstream refuge, 84 river miles downstream. The Umatilla River is only considered a CWR in late August and September when it is cooler than the Columbia River. The average temperature of the Umatilla River is warmer than the Columbia River in June and July, and the two rivers have the same average temperature of 20.8°C in August. In September, the Umatilla River is on average 1.9°C cooler than the Columbia River but has portions of the day that are more than 2°C cooler than the Columbia River, thereby providing intermittent CWR. This qualifies the Umatilla River as a marginal CWR (>18°C) for late August and September. ODEQ has designated the lower portion of the Umatilla River for salmon and trout rearing and migration and has assigned a water quality criterion of 18°C for maximum water temperatures. The maximum water temperature modeled for the Umatilla River is 27°C (1993-2011) (Appendix 12.18). Based on actual maximum temperature readings, the lower Umatilla River is on the 303(d) list for temperature impaired waters.

Photo 7-65 Umatilla River cold water refuge from western shore

With a mean August flow of 169 cfs, the Umatilla River CWR is estimated to have a volume of 46,299 m^3, the size of over 18 Olympic-sized swimming pools

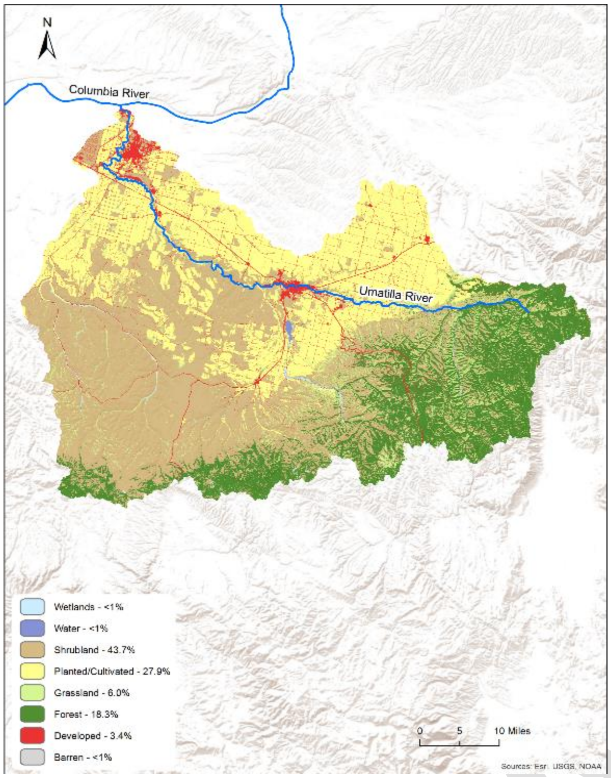


Figure 7-49 Land use in the Umatilla Basin

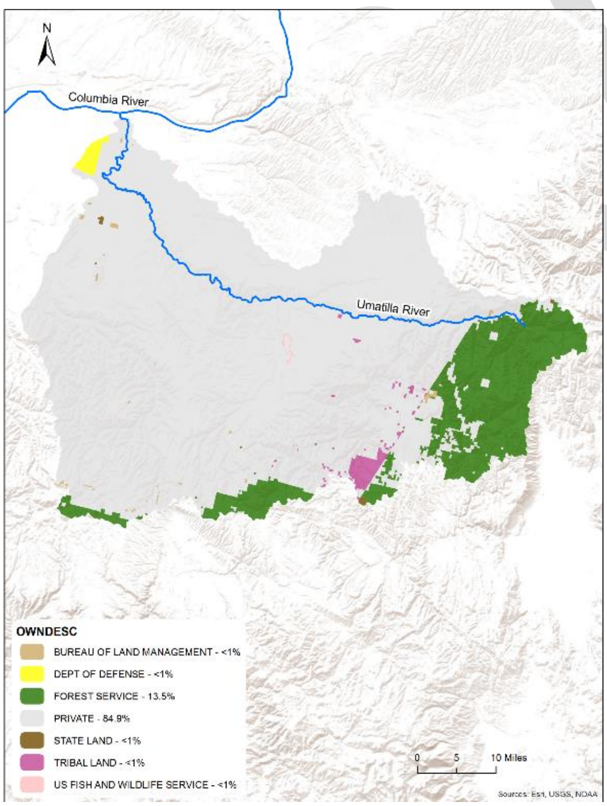


Figure 7-50 Land ownership in the Umatilla Basin

during the time the river is 2°C cooler than the Columbia River. The refuge consists of cool water within the lower tributary up to one mile upstream (***Figure 7-48***). The confluence is shallow and sandy.

Introduction to the Umatilla River Watershed

The Umatilla River headwaters originate 6,000 feet above sea level in the gently-sloping coniferous forests of the Blue Mountains. The river flows in a northwest direction, winding through an agricultural valley before joining the mainstem Columbia River. The basin characteristics that influence temperature are largely shaped by a long history of agricultural development. For instance, riparian vegetation along the Umatilla River and tributaries has been disturbed to facilitate agricultural land uses, which decreases riparian shading.

Ranching and agriculture predominate in the basin. Forest (18%) covers the higher elevation upper portions of the basin. In the gullies and hills of the southern portion of the watershed, shrubland (43%) grows extensively. Cultivated crops (28%) cover the flat lands north of the mainstem river and south of the Cities of Pendleton and Umatilla, located in the middle of the watershed and near the river mouth, respectively. Other than the road networks, these cities are the only developed (3%) land in the watershed (***Figure 7-49***).

The watershed is primarily under private ownership (85%). USFS (14%) manages portions of the watershed's forested upper reaches, and the Department of Defense controls a small section (<1%) of the basin near the river mouth. In addition, Confederated Tribes of the Umatilla Indian Reservation (CTUIR) land (<1%) covers a small portion of the basin (***Figure 7-50***).

In the 1980s and 1990s, flow restoration and fish passage projects were developed, leading to improved conditions in the confluence for salmonids. The most notable recent restoration project was the construction of a "water exchange" in the early 1990s that pumps warmer Columbia River water into the basin for irrigation in exchange for cooler Umatilla river water, previously diverted for agriculture, being left instream.

Factors that Influence Temperature in the Umatilla River Watershed

Riparian Vegetation: The loss of riparian vegetation in the Umatilla Basin – primarily due to agricultural development – has played a role in increasing stream temperatures. ***Figure 7-51*** shows the difference between existing and system potential shade, highlighting the riparian areas that should be targeted for revegetation. The areas with potential to increase riparian shade include Wildhorse Creek and the upper mainstem of the Umatilla River. The restoration of associated riparian wetlands would also contribute to increased water temperature buffering in the mainstem Umatilla River. Land in these subwatersheds is primarily made up of private agricultural land and private shrubland (***Figure 7-49***), rendering it highly important that there be funding and institutional capacity in the basin to develop revegetation opportunities with private landowners.

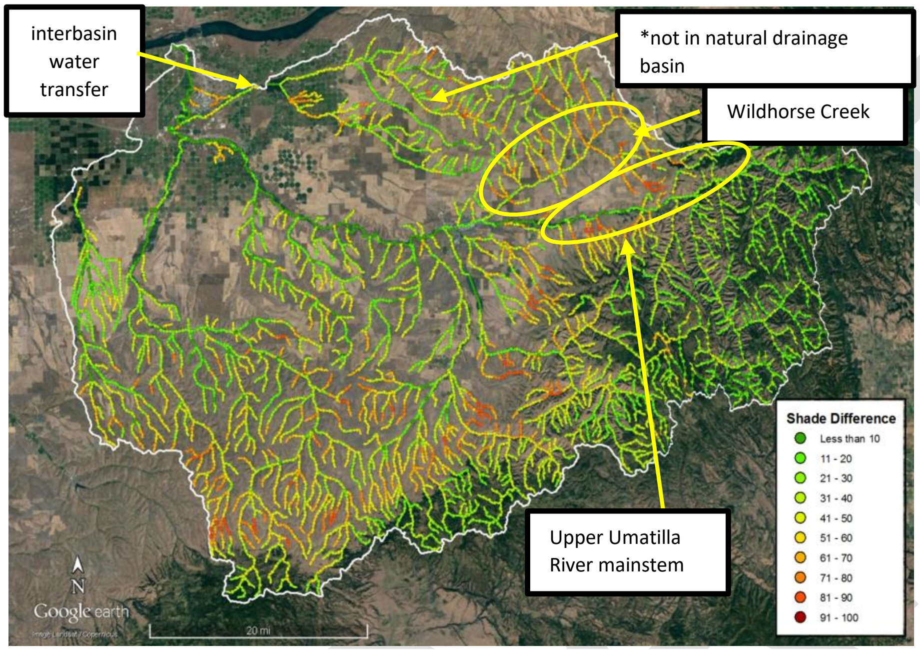


Figure 7-51 Umatilla River shade difference between potential maximum and current shade

Water quality modeling in ODEQ's *Umatilla River Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP)* (2001) predicted that maximum potential vegetation and restored flows could decrease water temperatures at the mouth from 24˚C to 21˚C under low flow conditions. The *CTUIR TMDL for Temperature and Turbidity* (2005) indicates that there is potential for temperature reduction between RM 56-82 on tribal land.

Hydromodification: There is one main storage reservoir in the Umatilla Basin, McKay Reservoir on McKay Creek, which captures winter flows to be delivered to farms in the summer through an extensive network of irrigation canals. A second storage reservoir, Cold Springs, is not within the natural drainage basin but is diverted into the lower watershed, impacting temperature at the confluence.

In the 1990s, two water exchange projects were built, which collectively pump 380 cfs of water up from the Columbia River into irrigation canals in exchange for an equal amount of Umatilla River water – that otherwise would have been diverted – left instream to benefit fish. These exchanges do not address unmet irrigation demands, but they do have beneficial implications for habitat within the basin and for CWR at the Columbia River confluence.

Water Use: The surface water in the Umatilla Basin – much of which is stored in two main storage reservoirs, McKay and Cold Springs – is over-appropriated, meaning that there are more water rights allocated in the basin than the river can satisfy during normal years. In the peak summer months, over 600% of the natural flow of the river is allocated for out-of-stream uses, over 88% of which is for irrigation and 11% of which is for municipal use (***Table 7-7***). Prior full implementation of the water exchanges, water withdraws primarily for irrigation led to very minimal to no Umatilla River flows reaching the Columbia River confluence during the summer irrigation season. Since implementation of the water exchanges and a 2006 agreement to provide for lamprey passage, Umatilla River flows are maintained throughout the summer. However, groundwater aquifers in the basin have been tapped for irrigation, resulting in significant declines in water tables in parts of the basin by more than 500 feet. Because of groundwater decline, the Umatilla Basin has four of Oregon's six Critical Groundwater Areas, leading the Oregon Water Resources Department to withhold the groundwater irrigation rights of over 120,000 acres of farmland in the basin, with the goal of steadying the declining groundwater table. The CTUIR have also expressed their concern over unmet claims to tribal reserved water rights, some of which they would likely put towards restoring river flows. Much of the river is diked or flanked by agriculture, which reduces floodplain connection and hyporheic flows. Efforts to conserve and increase water flows will help to cool water temperatures and increase CWR volume.

Table 7-7 Water Availability Analysis for the Umatilla River confluence with the Columbia River

UMATILLA R > COLUMBIA R - AT MOUTH (@ 50% exceedance)			
Month	Monthly Streamflow (cfs)		
	Natural Streamflow	Water Allocated or Reserved	% Allocated*
JUNE	323	1,043	323%
JULY	106	541	510%
AUGUST	65.7	399	607%
SEPTEMBER	74	488	659%
Top three users: Irrigation (88%), Municipal (11%), Industrial (0.07%)			
Water net positive January – April			
* % Allocated: [Water Allocated or Reserved]/[Natural Streamflow].This is the percentage of water either allocated or reserved for in-stream or other uses compared with the natural streamflow. Percentages over 100% indicate the water is overallocated at the mouth of the river.			
Reference: http://apps.wrd.state.or.us/apps/wars/wars_display_wa_tables/MainMenu1.aspx			

Climate Change: In 2040, average August temperatures in the Umatilla River are predicted to be 21°C compared to 22°C in the Columbia River. In 2080, August temperatures in the Umatilla River are expected to rise further to 22°C compared to 23°C in the Columbia River. If the Umatilla River is restored, there could be a greater difference between Umatilla and Columbia River water temperatures to make the Umatilla River a CWR.

Ongoing Activities in the Umatilla River Watershed and Recommended Actions to Restore the Cold Water Refuge

Restoration of the Umatilla CWR will involve a multifaceted effort focused on sustainable water use, riparian vegetation and riparian land management in the basin to balance human and ecological demands. There are ongoing efforts in eastern Oregon to find long-term, sustainable solutions to aging flood control levees, involving the CTUIR and bolstered by the Governor's Greater Eastern Regional Solutions Team. This initiative provides the opportunity to include enhancing riparian shade and floodplain function into decision making around levees. Other plans include ODFW's *Conservation and Recovery Plan for Oregon Steelhead Populations in* *the Middle Columbia River Steelhead Distinct Population Segment* (2010), NOAA's *Middle Columbia Steelhead ESA Recovery Plan* (2009), *Umatilla River Basin TMDL and WQMP,* and *CTUIR TMDL for Temperature and Turbidity* (2005).

With many pilot projects completed and local champions throughout the basin, there is momentum in the arena of voluntary environmental water transactions in the basin, with the Freshwater Trust playing a leadership role. These endeavors should be leveraged and prioritize projects which increase flow at the confluence. Actions to further restore the Umatilla Basin include:

- Consider set-back levees, as noted in the *Umatilla River Basin TMDL and WQMP,* to reduce channelization, restore natural channel complexity, reconnect the river with its floodplain, and restore groundwater interactions.
- Restore vegetation of riparian areas, primarily along Wildhorse Creek and the upper Umatilla River mainstem from the *Umatilla River Basin TMDL and WQMP* and *CTUIR TMDL for Temperature and Turbidity*.
- Continue to implement on-farm efficiency projects, water transactions and other means of restoring flow to the Umatilla River – particularly in August – which will help to cool river temperatures and expand CWR volume.

7.17 SUMMARY OF ACTIONS TO PROTECT AND RESTORE COLD WATER REFUGES

While EPA's analysis focused on the 12 primary CWR and two "restore" tributaries, all actions and recommendations in the following section can apply more broadly to any of the Lower Columbia River cold water tributaries that EPA originally identified in ***Table 2-1***.

Protect Through Regulatory Programs

All 12 primary CWR and two "restore" tributaries should be protected through the implementation of existing programs and regulatory actions that help keep waters cool. Since extensive portions of the 12 primary CWR tributaries include forest lands which contain many headwaters of the cold-water tributaries, important protective actions include continuing the implementation of U.S. Forest Service plans like the *USFS Gifford Pinchot National Forest Land and Resource Management Plan* and the *USFS Mount Hood National Forest Land and Resource Management Plan*, and state forest practice regulations.

Since additional water withdrawal during the summer can diminish the size and function of the primary 12 CWR tributaries, minimizing additional water withdrawals will help maintain CWR quality and function. Water quality standard updates, such as special designations, antidegradation policies, or narrative criteria could be a means for helping maintain current river temperatures in the primary CWR tributaries. Tributaries currently colder than the numeric temperature criteria that could warrant these additional protections include Tanner Creek, Eagle Creek, Herman Creek, Little White Salmon River, and the White Salmon River.

Restore Riparian Shade, Stream Morphology, and Instream Flow

Restoring degraded portions of the 12 primary CWR watersheds would enhance the quality of the CWR and to help counteract future increases in tributary river temperature from climate change. In addition, restoration of the two "restore" watersheds, consistent with current plans, would improve habitat and thermal conditions within the watershed, as well as increase the availability of CWR in the Lower Columbia River.

Specifically, funding and implementing plans for salmon recovery will help protect and restore CWR, as well as help meet temperature load allocations in watersheds with adopted Total Maximum Daily Loads. Tributaries with completed temperature TMDLs include the Sandy River, Wind River, Hood River, Klickitat River, Fifteenmile Creek, and the Umatilla River. Washington Department of Ecology is developing a watershed plan for temperature in the East Fork of the Lewis River. Restoration of the CWR in all primary and "restore" tributaries can be accomplished by the following actions, many of which are outlined in the salmon recovery plans and TMDLs:

1) *Restoring riparian shade*: Restoration of riparian shade should be targeted to those areas that have the greatest potential for increased shade in the watershed and are river reaches important for salmon habitat restoration.
2) *Restoring stream morphology and complexity, including narrower channels and increased pools*: Increasing the amount of instream large woody debris to create pools of cold water and trap sediment that would otherwise reach the river mouth will aid in keeping waters cool as they reach the tributary mouth and join the Columbia River.

3) *Implementing watershed conservation measures to restore summer flows*: Restoring summer flows is likely to involve a multi-stakeholder effort. Flows can be increased through flow conservation, water exchanges, trading, minimum instream flows, and dam releases.

Cool Water Releases from Dams

Upstream dams on the Cowlitz, Lewis, Sandy, and Deschutes Rivers can maintain and possibly increase the release of cold water to maintain or enhance the CWR at their confluences with the Columbia River. These dams, like the Merwin Dam on the Lewis River, can influence summer temperatures by releasing water from cooler depth within the storage reservoir and controlling summer release flows during times when flow is lowest, during late July through early September. Due to the Deschutes River's high CWR use by migrating salmonids, marginally cool current temperatures, and predicted temperature increases due to climate change, the potential to cool the river should be assessed.

Sediment Management

Sediment deposition may be a concern at the mouth of several CWR tributaries, including Herman Creek Cove, Wind River, White Salmon River, and the Klickitat River. Feasibility studies for sediment removal at the confluence areas should be considered to assess the potential for increased fish access, increased depth, and reduced thermal warming. Post-fire restoration activities should also be completed on Tanner and Eagle Creeks to promote bank stabilization and prevent further erosion and sediment buildup in the creek.

Protection and Enhancement of Non-Primary Cold Water Refuges

The protection and restoration actions described above should also be considered for the non-primary CWR to potentially increase the availability of CWR in those tributaries. As discussed in Chapter 2, most of these tributaries are relatively small with limited availability of CWR. The LCEP is working on a feasibility analysis of augmenting the availability of CWR for fish by building a log structure at the mouth of Oneonta Creek to deflect mainstem flow and create a pool of cold water at the mouth. Building this structure will help examine the potential for creating a larger volume of CWR at the mouth at Oneonta Creek and potentially other small cold streams in the Lower Columbia River.

7.18 ACTION TO ADDRESS FISHING IN COLD WATER REFUGES

As discussed in Chapter 4, fishing in CWR reduces the survival of steelhead that use CWR compared to those that do not, offsetting the benefits to fish using CWR. Information in this plan could be considered when updating fishing regulations in the primary CWR, especially during periods of warm Columbia River temperatures for the CWR with the highest use (Cowlitz River, Lewis River, Herman Creek Cove, Wind River, White Salmon River, Little White Salmon River (Drano Lake), Klickitat River, and Deschutes River).

8 UNCERTAINTIES AND ADDITIONAL RESEARCH NEEDS

This plan relies upon the most recent scientific studies, field observations, expert input, and analyses to characterize the amount of cold water refuges (CWR) in the Lower Columbia River and salmonid use of the CWR. However, the study of CWR use is an area with a lot of uncertainty because of the complex behaviors exhibited by salmonids. This section highlights some of the main uncertainties in this plan and recommends future studies to address them.

Adult Salmon and Steelhead Use of Cold Water Refuges below Bonneville Dam

There have not been any scientific studies characterizing fish use of CWR below Bonneville Dam. The extent different species of salmon and steelhead use the CWR areas below Bonneville Dam is unknown. In this plan, EPA relied on fishing boat presence in the confluence area of tributaries cooler than the Columbia River as the primary basis for qualifying use as a CWR in tributaries downstream of Bonneville Dam. EPA did, however, visually (from shore and snorkel) document presence of likely out-of-basin salmon and steelhead in the Tanner Creek CWR.

Study Recommendations: Fund a radio-tagging study to characterize salmon and steelhead use of CWR below Bonneville Dam. Install PIT-tag detectors near the mouth of the Cowlitz and Lewis Rivers.

Adult Salmon and Steelhead Use of Cold Water Refuges above Bonneville Dam

There have been extensive studies characterizing CWR use above Bonneville Dam conducted by the University of Idaho. EPA relied upon those studies in this plan. However, those studies were conducted in the late 1990s and early 2000s. There have been changes that may have altered the extent of CWR use since those studies were done. Those include an increased number of returning adult fall Chinook and steelhead, decreased percentage of returning adults that were transported as juveniles, increased sedimentation at the entrance of some CWR areas (e.g., White Salmon River), changes in thermal regime of CWR (e.g., Deschutes River), and increased mainstem Columbia River temperatures. Additionally, there has been very limited study of CWR use by sockeye and summer Chinook. This plan concludes CWR use by sockeye and summer Chinook is very limited, but studies would be beneficial to confirm the extent these species use CWR.

The installation of a PIT-tag detector at the mouth of the Deschutes River in 2013 is an investment that has provided valuable information on CWR use in the Deschutes River CWR. Installation of PIT-tag detectors at the mouth of other CWR would be beneficial for future analysis.

Study Recommendations: Fund a radio-tagging study to provide updated characterization of CWR use above Bonneville Dam under current conditions for Chinook, steelhead, and sockeye. Install PIT-tag detectors at the entrance to Drano Lake, Herman Creek Cove, White Salmon River, Klickitat River, Wind River, and Eagle Creek. Conduct a radio-tagging study after PIT-tag detectors are installed to calculate the detection efficiency of the detectors.

Benefits of Cold Water Refuge Use for Migrating Adult Salmon and Steelhead

As discussed in the plan, measuring the extent to which CWR use provides physiological benefits to migrating adult salmon and steelhead in terms of decreased mortality and other end points is confounded by fish harvest within CWR. Comparing survival rates of those fish that use CWR to those that don't shows higher survival rates for fish that don't, but the reduced survival can be explained by increased harvest levels in CWR. As noted in the plan, modeling predicts that CWR use can reduce energy loss and increase spawning success. CWR use may also provide a brief reprieve from exposure to warm Columbia River mainstem temperatures that may be beneficial by decreasing disease processes or reduced stress responses and increasing the success of adult migration, but this has not been documented.

Study Recommendations: Design and fund research studies to document and evaluate the benefits of CWR use to migrating adult salmon and steelhead.

Effects to Migrating Adult Salmon and Steelhead from Exposure to Elevated Columbia River Temperatures

The plan highlights analysis that shows a correlation between increased mainstem Columbia River temperatures and decreased adult migration survival through the Lower Columbia River. It also notes that some of the decreased survival could be attributed to fish moving into CWR as temperatures rise and being harvested. There are numerous studies documenting various adverse effects (mortality, disease, increased energy loss, decreased swimming speed, avoidance behavior) at temperature in excess of 18-20°C, but there are more studies on juveniles than adults due to challenges of conducting temperature effect studies on adult fish. Better quantification of mortality and adverse effects is needed for adult salmon and steelhead exposed to temperatures increments in the 20-25°C range for different durations in the Lower Columbia River.

Study Recommendations: Design and fund research studies to isolate the temperature-mortality relationship for migrating salmon and steelhead in the Lower Columbia River. Studies should also include assessment of the cumulative effects of elevated temperature for the entire return migration to spawning grounds.

Volumes of Cold Water Refuges

EPA relied upon modelling and, in some cases, measurement techniques to estimate the volume of CWR (steam and plume portion) in each of 23 CWR areas identified in this plan as described in the technical memoranda listed in this plan's appendices. There is significant variability around EPA's CWR volume estimates that EPA did not attempt to quantify. In addition to the uncertainty with the modelling and volume measurements, the actual amount of CWR varies throughout the day and season, depending on variable tributary and Columbia River temperatures, flow, and Columbia River water levels. EPA generalized CWR volume based on August mean tributary and Columbia River temperatures and flows. Further, EPA relied on modelled August mean stream temperatures (NorWeST) and flow (USGS).

Study Recommendations: All of the 12 primary CWR tributaries should have both temperature and flow monitors in the lower portion of the tributaries to track temperatures and flow over time and to provide input data for more detailed and variable estimates of CWR volume for future analysis.

Upstream Extent of Tributary Cold Water Refuge Use

Most of the 12 primary CWR do not have a barrier limiting how far upstream out-of-basin salmon and steelhead may travel. As described in Appendix 12.4, EPA relied on a variety of scientific lines of evidence to estimate the upstream extent that salmon and steelhead will use the tributary as a CWR, which included a radio-tagging study on the Deschutes River documenting that approximately 85% of out-of-basin steelhead used the lower five kilometers as CWR.

Study Recommendations: Install PIT-tag receivers approximately 3-5 kilometers upstream on the White Salmon, Klickitat, and Deschutes Rivers to document and track the extent out-of-basin salmon and steelhead use these tributaries as CWR.

Density Effects and Carrying Capacity of Cold Water Refuges

There is no research on the carrying capacity of CWR for adult salmon or steelhead. The closest research EPA could draw upon was observed fish density near spawning grounds or near the confluence of tributaries prior to ascending tributaries. It is therefore fairly speculative as to what densities cause fish to avoid or leave CWR. Also, high densities of adult fish are known to contribute to the spread of disease. This could be a concern for CWR that are colder than the Columbia River but are in the 18-20°C range, which are temperatures at which disease risk is elevated (e.g., Deschutes River). The extent to which CWR use at varying densities contributes to increase disease (and associated mortality) is unknown.

Study Recommendations: Design and fund a study to define the carrying capacity of CWR for salmon and steelhead, with particular focus on Drano Lake and Herman Creek which have barriers limiting the amount of CWR that is available for use.

Effects of Sediment Deposition on Cold Water Refuge Use

As discussed in this plan, sediment has deposited near the confluence areas of most the 12 primary CWR. This may have an effect on the extent to which salmon and steelhead use the CWR. As noted in Chapter 7, EPA recommends feasibility studies and implementation of projects to remove sediment in several CWR.

Study Recommendations: As part of any project to remove sediment from the CWR, a study should be designed to estimate the amount of CWR use before and after the sediment removal.

9 SUMMARY AND RECOMMENDATIONS

The following is a summary of EPA's Columbia River Cold Water Refuge plan. These findings and recommendations are grounded in the technical information found in this plan, the plan's technical appendices, and referenced scientific studies.

Lower Columbia River Temperatures

1. The water quality standard for the Lower Columbia River is 20°C, which is intended to minimize the risk of adverse effects to migrating salmon and steelhead from exposure to river temperatures that are warmer than 20°C.
2. Current daily average water temperatures in the Lower Columbia River (mouth to McNary Dam) exceed 20°C for approximately two months, from mid-July to mid-September, and exceed 21°C for approximately one month. River temperatures are typically the warmest in August with peak daily temperatures in the 22-23°C range.
3. Historically, pre-1940 Lower Columbia River summer temperatures were cooler, with August mean temperatures approximately 2–2.5°C cooler than the current August mean temperature of near 22°C. Both local anthropogenic sources (e.g., dams/reservoirs) and global climate change have contributed to this past warming.
4. Lower Columbia River summer temperatures are predicted to continue to get warmer. August mean temperatures are predicted to be near 23°C by 2040 and approximately 24°C by 2080.

Cold Water Refuges in the Lower Columbia River

5. There are 12 primary CWR in the Lower Columbia River in the lower portion and confluence area of 12 tributaries that flow into the Columbia River. These 12 CWR are known or presumed to be used by steelhead and fall Chinook and constitute 97% of CWR volume in the Lower Columbia River. In addition, there are 11 other tributaries that collectively provide a limited amount of CWR, are smaller in scale, and have limited information on fish use.
6. Four primary CWR are below Bonneville Dam (Cowlitz River, Lewis River, Sandy River, and Tanner Creek); five primary CWR are between Bonneville Dam and The Dalles Dam (Eagle Creek, Wind River, Herman Creek, White Salmon River, Little White Salmon River, and Klickitat River); and one primary CWR (Deschutes River) is between The Dalles Dam and the John Day Dam. There are no primary CWR between John Day Dam and McNary Dam.
7. The Cowlitz River, Lewis River, Little White Salmon River (Drano Lake), and the Deschutes River are the largest CWR.

Salmon and Steelhead Use of Cold Water Refuges

8. Summer steelhead and fall Chinook are the primary species that use CWR in the Lower Columbia River. Summer steelhead use CWR for extended periods (multiple weeks),

while fall Chinook use CWR for shorter periods (days to a week). Use of CWR is generally considered to be a successful migration strategy for these fish – lowering their overall temperature exposure by escaping peak Columbia River temperatures and allowing them to delay migration to when temperatures are cooler.

9. Duration of CWR use is very limited (hours) for summer Chinook, which may provide a brief respite from warm temperatures. Sockeye salmon do not appear to use CWR as a migration strategy, although tracking studies of sockeye CWR use has not been done. Extended use of CWR in the Lower Columbia River is generally considered to be an ineffective and ultimately unsuccessful migration strategy for these fish due to their run timing; extended CWR use would likely expose them to warmer Columbia and Snake River temperatures during the remaining part of their migration later in the summer.
10. Steelhead begin to use CWR when mainstem temperatures reach 19°C. Fall Chinook begin to use CWR when mainstem temperatures reach 21°C. Both species use CWR extensively when temperatures exceed 21°C.
11. CWR use by summer steelhead and fall Chinook likely provides physiological benefits by reducing the adverse effects associated with prolonged exposure to warm Columbia River temperatures. Prolonged exposure to warm temperatures increases disease risk, stress, loss of energy reserves, and mortality risk, and ultimately increases the probability of fish not being able to successfully spawn.
12. Peak use of Bonneville reservoir CWR by steelhead occurs mid-August through early September, and peak use by fall Chinook occurs in late August through mid-September. During an average year (river temperatures and run size), approximately 65,000 steelhead and 5,000 fall Chinook are in Bonneville reservoir CWR. During years with warm August-September Columbia River temperatures and high run size, as many as 155,000 steelhead and 40,000 fall Chinook are predicted to be in Bonneville reservoir CWR during the period of peak refuge use, although these peak numbers for steelhead and fall Chinook may not occur in the same years.
13. The number of salmon and steelhead in CWR each year is a function of summer Columbia River temperatures and run size – the larger the run size, the greater number of fish in CWR; and the warmer the Columbia River temperature, the greater proportion of the run using CWR.
14. CWR use appears to be a behavioral adaptation in response to increased summer Lower Columbia River temperatures. Under colder historical Columbia River temperatures, which exceeded 20°C for only a short period (a few days) and rarely exceeded 21°C, CWR use was likely to be significantly less than what occurs today. This hypothesis is supported by observations in recent years that show significantly less CWR use during years when Columbia River water temperatures are relatively cool.

Adverse Effects to Migrating Adult Salmon and Steelhead from Warm Columbia River Temperatures

15. Optimal Columbia River temperatures for migrating adult salmon and steelhead is below 18°C. At warmer river temperatures, increased stress, disease, mortality, and stored (fat) energy loss that can ultimately reduce spawning success, occur with increasing

severity as river temperatures rise above 20°C. At average river temperatures of 22-23°C, all adverse effects become significant.

16. Increased river temperature is correlated with decreased survival for migrating adult summer steelhead and fall Chinook between Bonneville Dam and McNary Dam. Survival rates decrease by about 7-10% at >21°C temperatures relative to temperatures below 20°C. Current CWR use by steelhead and fall Chinook may be minimizing survival loss by reducing exposure to >21°C temperatures. However, CWR use may also be contributing to survival loss from harvest in CWR.
17. River temperatures above 18°C reduce adult sockeye survival between Bonneville Dam and McNary Dam. Sockeye mortality rates are moderate at 18-20°C and are significant at 20-22°C river temperatures.
18. Due to increasing July temperatures in the Lower Columbia River over the past four to seven decades that are more frequently at levels that contribute to mortality, the migration timing of sockeye and summer Chinook has shifted to earlier in the year by approximately a week. Peak migration past Bonneville Dam for these fish is now in late June, with very few migrants in mid- to late July.
19. Absent use of CWR in the Lower Columbia River, a portion of the early fall Chinook exposed to warm Lower Columbia River temperature in August are predicted to lose energy reserves that result in total cumulative migration energy loss such that they cannot successfully spawn in the fall in the Snake River.

Sufficiency of Cold Water Refuges to Support Migrating Adult Salmon and Steelhead

20. EPA’s assessment is that the spatial and temporal extent of existing CWR appears to be sufficient under current and 20°C Columbia River temperatures but may not be in the future. Therefore, maintaining the current temperatures, flows, and volumes of the 12 primary CWR in the Lower Columbia River is important to limit significant adverse effects to migrating adult salmon and steelhead from higher water temperatures elsewhere in the water body.

21. Additional CWR in the Lower Columbia River may be needed due to the predicted continued gradual warming of the Columbia River. The 11 non-primary CWR tributaries and other potential tributaries may provide additional CWR through restoration and enhancement.

Watershed Characteristics of 12 Primary Cold Water Refuges

22. The 12 primary CWR tributaries are in watersheds with important characteristics and geographic features that serve to keep the tributaries relatively cool during the summer period. Some drain from the glaciers of Mount Rainier, Mount Adam, or Mount Hood, providing cold headwater source water (Cowlitz, Lewis, Sandy, Hood, White Salmon, Little White Salmon, Klickitat). Some have significant groundwater inflows that serve to keep the tributary cool (Tanner, Eagle, White Salmon, Little White Salmon, Klickitat, Deschutes). Ten of the tributary watersheds are in the central or western Cascades with high percentages of forested areas that minimize solar heating and keep waters cool.

23. Four of the primary tributaries (Cowlitz, Lewis, Sandy, Deschutes Rivers) have upstream storage dams that can influence summer temperatures by releasing water from cooler depth within the storage reservoir and by controlling summer release flows.
24. Although the 12 primary CWR tributaries are relatively cool, there are impacts within the watershed that can warm the tributary, including floodplain degradation, water withdrawals and reduced summer flow, sedimentation, and loss of riparian shade. Climate change has already warmed all tributaries to some extent and is predicted to continue to warm these tributaries in the future. Restoration of the anthropogenic impacts within the watershed can help offset predicted warming.
25. Most of the 12 primary tributaries have sediment build-up at the confluence with the Columbia River that may impede salmon and steelhead access to the CWR tributary, fill deep pools preferred by fish, and create shallow areas more susceptible to solar warming.

Recommended Actions to Protect and Restore Cold Water Refuges

26. Protect existing 12 primary CWR through the implementation of existing programs and regulatory actions that help keep waters cool.
    a. Since extensive portions of the priority CWR tributaries include forest lands, important protective actions include continued implementation of U.S. Forest Service plans and State Forest practice regulations.
    b. Since additional water withdrawal during the summer can diminish the size and function of the primary 12 CWR tributaries, minimize additional water withdrawals that would decrease summer flows.
    c. Consider special designations, antidegradation policies, and/or narrative water quality criteria as appropriate to prevent warming above current temperatures and maintain existing flows in the 12 priority CWR tributaries.
27. Restore degraded portions of the 12 primary CWR watersheds to enhance the quality of the CWR and to counteract predicted future increases in tributary river temperature by: 1) restoring riparian shade, 2) restoring stream morphology and complexity, including narrower channels and increased pools, and 3) implementing watershed conservation measures to restore summer flows.
28. Maintain or enhance cold water flows during late July through early September from upstream dams on the Cowlitz, Lewis, Sandy, and Deschutes Rivers to maintain or increase CWR. Due to the Deschutes River's high CWR use by migrating salmonids, marginally cool current temperatures, and predicted temperature increases due to climate change, the potential to cool the river should be assessed.
29. Consider feasibility studies for restoration and sediment removal at the confluence areas of the following watersheds to increase fish access to CWR and increase depth: Herman Creek Cove, Wind River, White Salmon River, and Klickitat River.
30. In addition to protecting and restoring portions of the 12 primary CWR tributaries, based on information provided in completed temperature TMDLs, EPA identified the Umatilla

River and Fifteenmile Creek as having the potential to provide increased CWR in the Lower Columbia River if thermally-degrading features of the watersheds were restored.

Recommended Action Regarding Fishing in Cold Water Refuges

31. Information in this plan could be considered when updating fishing regulations in the primary CWR, especially during periods of warm Columbia River temperatures for the CWR with the highest use (Cowlitz River, Lewis River, Herman Creek Cove, Wind River, White Salmon River, Little White Salmon River (Drano Lake), Klickitat River, and Deschutes River).

Recommended Studies to Address Uncertainties

32. In Chapter 8, several scientific uncertainties associated with this plan were highlighted with recommended future studies to address them, which include: radio-tag studies to track fish use of CWR below Bonneville Dam, repeated radio-tag studies to track fish use CWR above Bonneville Dam under current conditions, installation of PIT-tag detectors at the mouth of CWR tributaries, installation of temperature and flow gages near the mouth of all 12 CWR tributaries, and studies designed to better characterize the adverse effects of fish exposure to elevated temperatures in the Lower Columbia River and the associated benefits of CWR use to reduce the adverse effects.

10 REFERENCES

Berejikian, B. A., Tezak, E. P., & Schroder, S. L. (2001). Reproductive behavior and breeding success of captively reared Chinook salmon. *North American Journal of Fisheries Management*, *21*(1), 255-260.

Bowerman, T. E., Pinson-Dumm, A., Peery, C. A., & Caudill, C. C. 2017. Reproductive energy expenditure and changes in body morphology for a population of Chinook salmon Oncorhynchus tshawytscha with a long distance migration. *Journal of fish biology*, *90*(5), 1960-1979.

Connor, W. P., Tiffan, K. F., Chandler, J. A., Rondorf, D. W., Arnsberg, B. D., & Anderson, K. C. 2018. Upstream migration and spawning success of Chinook salmon in a highly developed, seasonally warm river system. *Reviews in Fisheries Science & Aquaculture*, 1-50.

Crozier, L. G., Scheuerell, M. D., & Zabel, R. W. 2011. Using time series analysis to characterize evolutionary and plastic responses to environmental change: a case study of a shift toward earlier migration date in sockeye salmon. *The American Naturalist*, 178(6), 755-773.

DART (Columbia River Data Access in Real Time). Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98101. http://www.cbr.washington.edu/dart

Fish Passage Center. 2014. Annual Report. BPA Contract #67312, BPA Project #1994-033-00. Fish Passage Center, Portland, Oregon.

Fish Passage Center. 2015. Memorandum from Fish Passage Center Staff, to Mary Lou Soscia, EPA; Christine Psyk, EPA; and John Palmer, EPA, re: Information regarding 2015 conditions at Bonneville Dam. Fish Passage Center, Portland, Oregon. August 26, 2015.

Fish Passage Center. 2015. Memorandum from Michele DeHart, Fish Passage Center, to Charles Morrill, WDFW; Erick VanDyke, ODFW, and Steven Hawley, citizen, re: Requested data summaries and actions regarding sockeye adult fish passage and water temperature issues in the Columbia and Snake Rivers. Fish Passage Center, Portland, Oregon. October 28, 2015.

Fish Passage Center. 2016. Annual Report. BPA Contract #7075, BPA Project #1994-033-00. Fish Passage Center, Portland, Oregon.

Fish Passage Center. 2016. Memorandum from Michele DeHart, Fish Passage Center, to John Palmer, U.S. Environmental Protection Agency, re: The effect of water temperature on steelhead upstream passage. Fish Passage Center, Portland, Oregon. October 31, 2016.

Fish Passage Center. 2016. Memorandum from Michele DeHart, Fish Passage Center, to Charles Morrill, WDFW, and Erick VanDyke, ODFW, re: Requested data summaries regarding summer Chinook adult fish passage and water temperature in the Columbia and Snake River. Fish Passage Center, Portland, Oregon. January 29, 2016.

Fish Passage Center. 2018. Memorandum from Michele DeHart, Fish Passage Center, to John Palmer, U.S. Environmental Protection Agency, re: Fall Chinook survival between Bonneville and McNary Dams, and the relationship between water temperature, travel velocity, and arrival timing. Fish Passage Center, Portland, Oregon. May 8, 2018.

Goniea, T. M., Keefer, M. L., Bjornn, T. C., Peery, C. A., Bennett, D. H., & Stuehrenberg, L. C. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. *Transactions of the American Fisheries* Society, 135(2), 408-419.

High, B., Peery, C. A., & Bennett, D. H. 2006. Temporary staging of Columbia River summer steelhead in coolwater areas and its effect on migration rates. *Transactions of the American Fisheries Society*, *135*(2), 519-528.

Isaak, D., S. Wenger, E. Peterson, J. Ver Hoef, D. Nagel, C, Luce, S. Parkes-Payne. 2017. The NorWeST summer stream temperature model and scenarios for the western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. Water Resources Research, 53, 9181–9205. https://doi.org/10.1002/2017WR020969

Isaak, D., S. Wenger, E. Peterson, J. Ver Hoef, D. Nagel, C. Luce, S. Hostetler, J. Dunham, B. Roper, S. Wollrab, G. Chandler, D. Horan, S. Parkes-Payne. 2018. Global Warming of Salmon and Trout Rivers in the Northwestern U.S.: Road to Ruin or Path Through Purgatory? Transactions of the American Fisheries Society. 147(3): Pages 566-587. https://doi.org/10.1002/tafs.10059.

Jepson, M.A., Keefer, M.L., Naughton, G.P., Peery, C.A., and Burke, B.J. 2010. Population composition, migration timing, and harvest of Columbia River Chinook salmon in late summer and fall. North American Journal of Fisheries Management. 30: 72-88.

Keefer, M. L., Peery, C. A., Bjornn, T. C., Jepson, M. A., & Stuehrenberg, L. C. 2004. Hydrosystem, dam, and reservoir passage rates of adult Chinook salmon and steelhead in the Columbia and Snake rivers. *Transactions of the American Fisheries Society*, *133*(6), 1413-1439.

Keefer, M. L., Caudill, C. C., Peery, C. A., & Bjornn, T. C. 2006. Route selection in a large river during the homing migration of Chinook salmon (Oncorhynchus tshawytscha). *Canadian Journal of Fisheries and Aquatic Sciences*, *63*(8), 1752-1762.

Keefer, M. L., Peery, C. A., & High, B. 2009. Behavioral thermoregulation and associated mortality trade-offs in migrating adult steelhead (Oncorhynchus mykiss): variability among sympatric populations. *Canadian Journal of Fisheries and Aquatic Sciences*, *66*(10), 1734-1747.

Keefer, M.L., Jepson, M.A., Clabough, T.S., & Caudill, C.C. 2017. Migration of adult salmonids in the federal Columbia River hydrosystem: a summary of radiotelemetry studies, 1996-2014. Prepared for U.S. Army Corps of Engineers, Portland District. Technical Report, 2017-2.

Keefer, M.L., & Caudill, C.C. 2017. Assembly and analysis of radiotelemetry and temperature logger data from adult Chinook salmon and steelhead migrating through the Columbia River Basin. Prepared for Tetra Tech and the U.S. Environmental Protection Agency. Technical Report 2017-1.

Keefer, M.L., Jepson, M.A., Clabough, T.S., Johnson, E.L., & Caudill, C.C. 2015. Reach conversion rates of radio-tagged Chinook and sockeye salmon and steelhead in the Lower Columbia River (A Report for Study Code ADS-P-13-2). Prepared for U.S. Army Corps of Engineers, Portland District. Technical Report 2015-8.

Keefer, M. L., Clabough, T. S., Jepson, M. A., Johnson, E. L., Peery, C. A., & Caudill, C. C. 2018. Thermal exposure of adult Chinook salmon and steelhead: Diverse behavioral strategies in a large and warming river system. *PloS one*, *13*(9), e0204274.

Lower Columbia River Estuary Partnership. (n.d.) Lower Columbia River Thermal Refugia Study: Results Summary for 2014-2015 Columbia River Gorge Stream Temperature Monitoring.

McCullough, D. 1999. A Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon. Prepared for the U.S. Environmental Protection Agency. EPA 910-R-99-010. Columbia River Inter-Tribal Fish Commission, Portland, OR.

National Research Council. 2004. *Managing the Columbia River: Instream flows, water withdrawals, and salmon survival*. National Academies Press.

Naughton, G. P., Jepson, M. A., Peery, C. A., Brun, C. V., & Graham, J. C. 2009. Effects of temporary tributary use on escapement estimates of adult fall Chinook salmon in the Deschutes River, Oregon. *North American Journal of Fisheries Management*, *29*(6), 1511-1518.

NOAA Fisheries. 2014. Endangered Species Act Section 7(a)(2) Supplemental Biological Opinion, Consultation on Remand for Operation of the Federal Columbia River Power System. NWR-2013-9562. National Marine Fisheries Service, Northwest Region.

NOAA Fisheries. 2016. 2015 Adult Sockeye Salmon Pass Report. National Marine Fisheries Service.

NOAA Fisheries. 2017a. Use of the Deschutes River by Migrating Adult Snake River Steelhead. National Marine Fisheries Service. Draft.

NOAA Fisheries. 2017b. Supplemental Recovery Plan Module for Snake River Salmon and Steelhead – Mainstem Columbia River Hydropower Projects. National Marine Fisheries Service.

NOAA Fisheries. 2019. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the Continued Operation and Maintenance of the Columbia River System. WCRO-2018-00152. National Marine Fisheries Service.

Plumb, J. M. 2018. A bioenergetics evaluation of temperature-dependent selection for the spawning phenology by Snake River fall Chinook salmon. Ecology and Evolution, 8(19), 9633-9645.

Richter, A., & Kolmes, S. A. 2005. Maximum temperature limits for Chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries science, 13(1), 23-49.

Robards, M. D., & Quinn, T. P. 2002. The migratory timing of adult summer-run steelhead in the Columbia River over six decades of environmental change. *Transactions of the American Fisheries Society*, *131*(3), 523-536.

Snyder, M. N., Schumaker, N. H., Ebersole, J. L., Dunham, J. B., Comeleo, R. L., Keefer, M. L., ... & Palmer, J. 2019. Individual based modeling of fish migration in a 2-D river system: model description and case study. *Landscape Ecology*, *34*(4), 737-754.

USACE (U.S. Army Corps of Engineers). 2013. Location and use of adult salmon thermal refugia in the Lower Columbia and lower Snake Rivers. Federal Columbia River Power System, Amendment 1 of the Supplemental FCRPS BiOp.

USACE (U.S. Army Corps of Engineers). 2017. Endangered Species Act. Federal Columbia River Power System, 2016 Comprehensive Evaluation. U.S. Army Corps of Engineers Northwestern Division, Bureau of Reclamation Pacific Northwest Region, and Bonneville Power Administration.

U.S. Environmental Protection Agency. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

U.S. Environmental Protection Agency. 2018. Assessment of Impacts to Columbia and Snake River Temperatures using the RB10 Model. Preliminary Draft December 2018. EPA Region 10.

Yearsley, J. R. 2009. A semi-Lagrangian water temperature model for advection-dominated river systems. *Water Resources Research*, *45* (12).

11 CHAPTER 7 BIBLIOGRAPHY

Applicable to all snapshots:

2017a. USFS and EPA. *NorWeST model runs and analysis from Chapter 1.*

2017b. EPA. *Draft Shade Images North*.

2017c. EPA. *Land Use and Ownership Maps.*

COWLITZ RIVER

2017. Cowlitz County. *Cowlitz County Comprehensive Plan: 2017 Update.*

2015. Climate Impacts Group, University of Washington. *Climate Change Impacts on Tacoma Power Watersheds.*

2014. Lower Columbia Fish Recovery Board. *WRIA 26 Water Supply and Stream Flow Review: Findings and Recommendations.*

2012. WA Department of Ecology. *Focus on Water Availability: Cowlitz Watershed, WRIA 26.*

2004. Lower Columbia Fish Recovery Board. *Grays-Elochoman and Cowlitz Watershed Management Plan*.

2004. Lower Columbia Fish Recovery Board. *Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan: Lower Cowlitz.*

2004. Lower Columbia Fish Recovery Board. *Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan: Upper Cowlitz.*

Websites:

Capitol Land Trust. Cowlitz River Preserve: https://capitollandtrust.org/conserved-lands/conservation-areas/cowlitz-watershed/cowlitz-river-preserve/

Tacoma Public Utilities. Cowlitz River Project: https://www.mytpu.org/tacomapower/about-tacoma-power/dams-power-sources/hydro-power/cowlitz-river-project/

TDN.com. *"Cowlitz river deepens slightly for first time since Mount St. Helens eruption:"* https://tdn.com/news/local/cowlitz-river-deepens-slightly-for-first-time-since-mount-st/article_400a5b8c-bdd0-11e3-b2c9-001a4bcf887a.html (April 7, 2014)

The Daily Chronicle. *"Commentary: Climate, Carbon and an Uncertain Future for the Cowlitz and other Waterways:"* http://www.chronline.com/opinion/commentary-climate-carbon-and-an-uncertain-future-for-the-cowlitz/article_eea6795a-ffa8-11e7-b9f2-cbfc9696de91.html (January 22, 2018)

WA Department of Fish and Wildlife. Cowlitz Wildlife Area: https://wdfw.wa.gov/lands/wildlife_areas/cowlitz/

LEWIS RIVER

2016. WA Department of Ecology. *Focus on Water Availability: Lewis River Watershed, WRIA 27.*

2010. Lower Columbia Fish Recovery Board. *North Fork Lewis Washington Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan.*

2010. Lower Columbia Fish Recovery Board. *East Fork Lewis Washington Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan.*

2008. Washington Administrative Code. *Water Resources Management Program for the Lewis Basin, WRIA 27*.

Websites:

Columbia River Images. Lewis River, Washington: http://columbiariverimages.com/Regions/Places/lewis_river.html

PacifiCorp. Lewis River: http://www.pacificorp.com/lewisriver

Lewis River: http://www.lewisriver.com/

USGS. Lakes and Drainages Around Mount St. Helens: https://volcanoes.usgs.gov/volcanoes/st_helens/st_helens_geo_hist_107.html

SANDY RIVER

2017. Sandy River Basin Watershed Council. *State of the Sandy*.

2015. U.S. Army Corps of Engineers. *Sandy River Delta Dam Removal Project*. Powerpoint presentation.

2013. U.S. Army Corps of Engineers. *Environmental Assessment Sandy River Delta Section 536 Ecosystem Restoration project, Multnomah County.*

2012. USGS. *Geomorphic Response of the Sandy River, Oregon, to Removal of Marmot Dam*.

2010. Oregon Fish and Wildlife. *Oregon Lower Columbia Plan*.

2008. Portland Water Bureau. *Bull Run Water Supply Habitat Conservation Plan*.

2005. Oregon Department of Environmental Quality. *Sandy River Basin Total Maximum Daily Load*.

1994. USFS. *Upper Sandy National Wild and Scenic River Management Plan.*

1993. Bureau of Land Management. *Sandy River Wild and Scenic River and State Scenic Waterway Management Plan.*

Websites:

Columbia River Gorge National Scenic Area, Sandy River Delta. USFS. https://www.fs.usda.gov/recarea/crgnsa/recarea/?recid=29976

Friends of the Sandy River Delta. http://fsrd.org/

National Wild and Scenic River System, Sandy River, Oregon. USFS. https://www.rivers.gov/rivers/sandy.php

Partnerships in the Sandy River. USFS. https://www.fs.usda.gov/detail/r6/workingtogether/?cid=STELPRDB5200643

Sandy River Basin Partnership: Case Study by Freshwater Trust. https://www.thefreshwatertrust.org/case-study/sandy-river-basin-partnership/

Sandy River Basin Watershed Council. http://sandyriver.org

Sandy River Delta dam removal. U.S. Army Corps of Engineers. http://www.nwp.usace.army.mil/Missions/Current/Sandy-River-Delta/

Sandy River Water Trail Paddle Guide. City of Sandy. https://www.ci.sandy.or.us/Sandy-River-Water-Trail/

TANNER CREEK

2018. EPA. *EPA Region 10 Internal Memo re: Estimated the extent of riparian disturbance resulting from the 2017 Eagle Creek Fire.* To: Jenny Wu. Author: Peter Leinenbach. Date: 12/10/2018.

1978. Oregon Water Resources Department. Water Right Permit No. G 5646 (Certificate No. 45793). Retrieved from: https://apps.wrd.state.or.us/apps/wr/wrinfo/wr_details.aspx?snp_id=98192 on July 17, 2019.

1962. Oregon Water Resources Department. Water Right Permit No. S 1310 (Certificate No. 30039). Retrieved from: https://apps.wrd.state.or.us/apps/wr/wrinfo/wr_details.aspx?snp_id=82433 on July 17, 2019.

EAGLE CREEK

2017. OWRD. *Water Availability Analysis Eagle Creek > Columbia River – At Mouth, Hood Basin.http://apps.wrd.state.or.us/apps/wars/wars_display_wa_tables/display_wa_complete_report.aspx?ws_id=30410510&exlevel=50&scenario_id=1*.

1990. USFS. *Mount Hood Forest Land Resources Management Plan*

Websites:

USFS Mount Hood National Forest Land and Resources Management website. https://www.fs.usda.gov/land/mthood/landmanagement

ODEQ. Figure 160A: Fish Use Designations Map, Hood Basin, Oregon. https://www.oregon.gov/deq/Rulemaking%20Docs/figure160a.pdf

HERMAN CREEK

2017. Conversations with Port of Cascade Locks. (July, August 2017)

2010. Cramer Fish Sciences. *Temperature Characteristics of Herman Creek Cove and its Function as a Cool-Water Refuge for Adult Salmon and Steelhead in the Columbia River.*

2008. ODFW. *Oxbow Hatchery Program Management Plan*.

2004. Hood River Soil and Conservation District. *Hood River Subbasin Plan Including Lower Oregon Columbia Gorge Tributaries*.

USFS. Herman Creek Trail #406. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5397010.pdf

WIND RIVER

2017a. Underwood Conservation District. *Landowner Handbook: A Guide to Best Management Practices in Skamania and Klickitat Counties*.

2017b. Underwood Conservation District, Lower Columbia Fish Recovery Board, Wind River Work Group. *Wind River Habitat Restoration Strategy*. Inter-fluve.

2017c. Washington Department Fish and Wildlife. *Abundance and Productivity of Wind River Steelhead and Preliminary Assessment of their Response to Hemlock Dam Removal, 2016, BPA Project #: 1998-019-00*.

2015. Washington Department Fish and Wildlife. *Abundance and Productivity of Wind River Steelhead and Preliminary Assessment of their Response to Hemlock Dam Removal, 2015, BPA Project #: 1998-019-00*.

2014. R.A. Lovett. *Dam removals: Rivers on the run*. Nature.

2013. USGS. Wind River subbasin restoration: U.S. Geological Survey annual report November 2012 through December 2013.

2012. Washington Department of Ecology. *Focus on Water Availability: Wind-White Salmon Watershed, WRIA 29.* Publication No. 11-11-033.

2012. USGS. *Wind River Watershed Restoration Annual Report*, November 2011.

2008. Washington Department of Ecology. *Table 3: Goals and Accomplishments Associated with Wind River Temperature Total Maximum Daily Load Daily Implementation Plan*.

2004. Washington Department of Ecology. *Wind River Watershed Temperature Total Maximum Daily Load: Detailed Implementation Plan.* Publication No. 04-10-037.

2002. Washington Department of Ecology. *Wind River Watershed Temperature Total Maximum Daily Load.* Publication No. 02-10-029.

2004. Lower Columbia Fish Recovery Board. *Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan*.

Lower Columbia Fish Recovery Board. Wind River Restoration Workgroup. https://www.lcfrb.gen.wa.us/windriver.

USFS. Wind River Stream Restoration Cost Estimates.

USFS. Wind River Watershed Restoration Projects Annual Reports 2000-2002.

LITTLE WHITE SALMON RIVER

2004a. Lower Columbia Fish Recovery Board (LCFRB). *Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plans Volume II Subbasin Plan Chapter K Little White Salmon*.

2004b. Columbia River Inter-Tribal Fish Commission (CRITFC). *Little White Salmon River Subbasin Plan Summary.* http://plan.critfc.org/vol2/subbasin-plans/little-white-salmon-river/

2004c. Northwest Power and Conservation Council. *Volume II, Chapter 17 Little White Salmon Sub-basin.* https://www.nwcouncil.org/sites/default/files/Vol._II_Ch._17_Little_White_Salmon.pdf

2000. Prepared for the Northwest Power Planning Council by Dan Rawding at the WA Department of Fish and Wildlife. *NWCP- Little White Salmon River Subbasin Summary*.

Undated. Northwest Power and Conservation Council. Little White Salmon Subbasin Dashboard. https://app.nwcouncil.org/ext/dashboard/sb.asp?20

Undated. WQS. Chapter 173-201A WAC Water Quality Standards for Surface Waters of the State of Washington. https://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A. Accessed 8/1/2016.

WHITE SALMON RIVER

2016. *Salmon and Steelhead in the White Salmon River after the Removal of Condit Dam—Planning Efforts and Recolonization Results*. Fisheries, Vol. 41, No. 4

2015. USGS & U.S. Department of Interior. *Salmon Habitat Assessment for Conservation Planning in the Lower White Salmon River, Washington*.

2013. Klickitat County Natural Resource Department. *Klickitat Lead Entity Region - Salmon Recovery Strategy*. John Foltz.

2013. Mid-Columbia Fisheries Enhancement Group. *Literature Review of Mainstem Columbia River Anadromous Salmonid Habitat and Restoration Potential Between Bonneville Dam and the Yakima River Confluence*.

2012. Washington Department of Ecology. Wind-White Salmon Watershed, *WRIA 29: Focus on Water Availability*, 11-11-033.

2009. NOAA Fisheries. *Appendix B: Recovery Plan for the Klickitat Population of Middle Columbia River Steelhead Distinct Population Segment*.

Yakama Nation Fisheries. *Underwood In-Lieu Navigation and Habitat Restoration Project*

HOOD RIVER

2018. ODEQ. *Western Hood Subbasin Temperature TMDL, revised*.

2016. Water Professionals Network for Hood River Basin SWCD. *Hood River Basin Water Conservation Strategy*.

2014. Hood River Watershed Group. *Hood River Watershed Action Plan.*

2014. CRITFC. *Spirit of the Salmon: Wy-Kan-Ush-Mi Wa-Kish-Wit, 2014 update*.

2006. USDA/USFS Mount Hood National Forest. *Hood River Aquatic Habitat Restoration Strategy*.

2004. Hood River SWCD. *Hood River Subbasin Plan*.

2001. ODEQ. *Western Hood Subbasin TMDL*.

1999. Hood River Soil and Water Conservation District. *Hood River Watershed Assessment*.

Websites:

Hood River SWCD: http://hoodriverswcd.org/hrwg/

Columbia Land Trust, Powerdale Dam: https://www.columbialandtrust.org/project/hood-river/

KLICKITAT RIVER

2013. Environ for WRIA 30 Watershed Planning and Advisory Committee, Klickitat County, Central Klickitat Conservation District. *Thermal Refuges and Fish Habitat Assessment, WRIA 30*.

2013. Klickitat County Natural Resources Department. *Klickitat Lead Entity Region-Salmon Recovery Strategy*.

2012. Washington Department of Ecology. *Klickitat Watershed, WRIA 30: Focus on Water Availability*. Publication 11-11-034.

2009. NOAA Fisheries. NOAA Fisheries Salmon Recovery Plan.

2008. Narum, S.R. et al. *Influence of landscape on resident and anadromous life history O. mykiss.* Canadian Journal of Fisheries and Aquatic Sciences 65:1013-1023.

2008. Yakama Nation in cooperation with WDFW. *Klickitat River Anadromous Fisheries Master Plan.*

2007. WRIA 30 Water Resource Planning and Advisory Committee. *Framework for Water management in WRIA 30 Klickitat River Watershed.*

2005. Klickitat County, Yakima County, City of Goldendale, PUD No. 1 of Klickitat County. *Klickitat River Basin Watershed Management Plan*.

2004. BPA. *Yakama/Klickitat Fisheries Project-Klickitat Only Monitoring and Evaluation, 2003-2004 Annual Report.* Publication DOE/BP-00014033-1.

2003. Sampson, M., & Evenson, R. *Yakima/Klickitat Fisheries Project; Klickitat Only Monitoring and Evaluation, 2002-2003 Annual Report* (No. DOE/BP-00005934-1). Bonneville Power Administration (BPA), Portland, OR.

2003. Aspect Consulting for Klickitat County. *Multipurpose Water Storage Screening Assessment Report WRIA 30.*

2002. Washington Department of Ecology. *Little Klickitat River Watershed Temperature Total Maximum Daily Load*. Publication 02-03-031.

Undated. NOAA Fisheries. *Northwest Salmon & Steelhead Recovery Planning & Implementation: Middle Columbia River Steelhead DPS Recovery Plan Summary.* *https://docs.lib.noaa.gov/noaa_documents/NOAA FISHERIES/Middle_Columbia_steelhead_DPS_plan_summary.pdf*

Undated. Klickitat County. Links to Klickitat River Planning Documents. *http://www.klickitatcounty.org/239/WRIA-30---Klickitat-Planning-Documents*

Websites:

Columbia Land Trust. https://www.columbialandtrust.org/news/project/klickitat-white-salmon-rivers/

FIFTEENMILE CREEK

2010a. United States Department of Agriculture. *Fifteenmile Creek Basin Aquatic Habitat Restoration Strategy.* Mount Hood National Forest, Barlow Ranger District, Dufur, Oregon.

2010b. Oregon Department of Fish and Wildlife. *Conservation and Recovery Plan for Oregon Steelhead Populations in the Middle Columbia River Steelhead Distinct Population Segment.*

2008. Oregon Department of Environmental Quality. *Middle Columbia-Hood (Miles Creeks) Total Maximum Daily Load.*

2004. Graves, R. *Fifteenmile Creek Riparian Buffers Project, 2002-2003 Annual Report,* Project No. 200102100, 10 electronic pages, (BPA Report DOE/BP-00004935-2)

2003. Wasco County Soil and Water Conservation District, for Fifteenmile Watershed Council. *Fifteenmile Watershed Assessment.*

Oregon Water Resources Department. 5/29/2013. Presentation on *"Groundwater Supplies in the Fifteenmile Creek Drainage, The Dalles, Oregon."*

Fifteenmile Watershed Council. 1/25/2012. *Endangered Species Act Workshop Meeting Minutes.*

Websites:

The Freshwater Trust. 6/14/2018. *"Grant lays foundation for alert system to protect fish."* https://www.thefreshwatertrust.org/grant-lays-foundation-for-alert-system-to-protect-fish/?utm_source=June%20BlueNews

National Wild and Scenic Rivers System. *Fifteenmile Creek, Oregon.* https://www.rivers.gov/rivers/fifteenmile.php

DESCHUTES RIVER

2016. McMillan, G., Hafele, R., Bond, J., Faux, R., Diabat, M. *Airborne Thermal Infrared Remote Sensing of the Lower Deschutes River*. Deschutes River Alliance.

2013. French, R., Stuart, A., Hooton, B., Dale, C. *White Paper – 2013 Lower Deschutes River Temperatures and Fisheries*. Oregon Fish and Wildlife.

2006. High, B., C. A. Peery, and D. H. Bennett. *Temporary staging of Columbia River summer steelhead in coolwater areas and its effect on migration rates.* Transactions of the American Fisheries Society 135(2):519-528.

2005. Northwest Power and Conservation Council [NPCC]. *Deschutes Subbasin Plan*. https://www.nwcouncil.org/fw/subbasinplanning/deschutes/plan.

2003. O'Connor, J. and Grant, G. *A Peculiar River: Geology, Geomorphology, and Hydrology of the Deschutes River, Oregon*. American Geophysical Union, Washington, D.C.

Websites:

Deschutes River Conservancy. http://www.deschutesriver.org/about-us/.

NorWeST Regional Database and Modeled Stream Temperatures. https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

Portland General Electric. "Deschutes Fish Runs." https://www.portlandgeneral.com/corporate-responsibility/environmental-stewardship/water-quality-habitat-protection/fish-counts-fish-runs/deschutes-fish-runs.

Upper Deschutes Watershed Council. http://www.upperdeschuteswatershedcouncil.org/.

UMATILLA RIVER

2016. Pagel, Martha. AMP Insights. *Oregon's Umatilla Basin Aquifer Recharge and Basalt bank.* Case Study for: Political Economy of Water Markets.

2015. Confederated Tribes of the Umatilla Indian Reservation. *Draft Agricultural Management Environmental Assessment.* http://ctuir.org/system/files/AG%20Mg%20Plan%207_28_2015_0.pdf

2001. Oregon Department of Environmental Quality. *Umatilla River Basin Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP)*.

Websites:

Bureau of Reclamation. *Umatilla Basin Project.* https://www.usbr.gov/projects/index.php?id=410

12 APPENDICES

12.1 LOWER COLUMBIA RIVER TEMPERATURE VARIATION

12.2 EVALUATION OF THE POTENTIAL COLD WATER REFUGIA CREATED BY TRIBUTARIES WITHIN THE LOWER/MIDDLE COLUMBIA RIVER BASED ON NORWEST TEMPERATURE MODEL

12.3 SCREENING APPROACH TO IDENTIFY THE 23 TRIBUTARIES THAT CURRENTLY PROVIDE CWR IN THE LOWER COLUMBIA RIVER

12.4 LOCATION OF UPSTREAM EXTENT OF 23 CWR AREAS USED BY MIGRATING SALMON AND STEELHEAD

12.5 VOLUME OF COLD WATER REFUGE ASSOCIATED WITH THE 23 TRIBUTARIES PROVIDING CWR IN THE LOWER COLUMBIA RIVER AND SELECTION OF THE 12 PRIMARY CWR

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