Appendix K
Effects of Temperature Reduction and Flow Augmentation on Spring-run Chinook Salmon

EFFECTS OF TEMPERATURE REDUCTION AND FLOW AUGMENTATION ON SPRING-RUN CHINOOK SALMON

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Introduction

This memorandum describes the range of potential responses anticipated for spring-run Chinook salmon (*Oncorhynchus tshawytscha*) to the physical changes to the environment created by a proposed flood retention flow augmentation (FRFA) facility in the upper Chehalis Basin (about 1 mile south of Pe Ell, Washington). Specifically, it focuses on the potential responses of spring-run Chinook salmon to flow augmentation with cooler water during late spring through early fall. Releasing cool water downstream of dams has been shown to support population productivity in some rivers by providing returning adult salmon with cool water refugia and reducing pre-spawning mortality. The summary does not address other impacts of a dam on Chinook salmon in detail, such as the loss of spawning habitat or changes in substrate coarseness downstream of the dam.

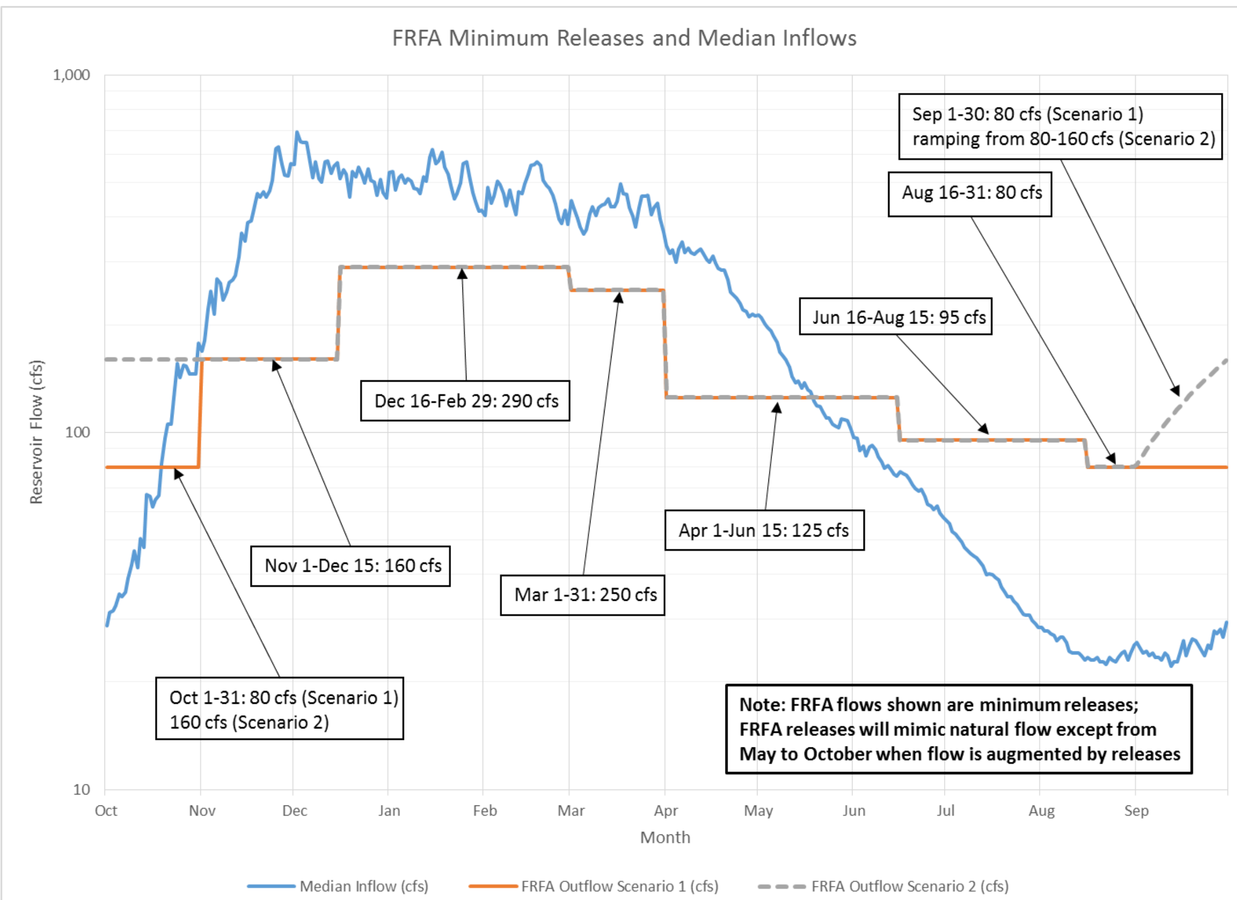
This memorandum summarizes different types of information useful for anticipating responses of spring-run Chinook salmon to temperature reduction and flow augmentation below a potential FRFA dam in the Chehalis River. It includes information on similar situations in other river systems, empirical data available for the Chehalis River, including direct observations of temperature and spring-run Chinook salmon behavior in summer, and a range of estimates of the change in habitat potential with an FRFA dam.

The Ecosystem Diagnosis & Treatment (EDT) model was used to estimate how salmon respond to changes in habitat conditions below the FRFA when cool water is released. EDT models the potential for habitat to support salmon and steelhead production. It does not model how fish behave or may change their behaviors, in this case associated with the release of cool water. Any behavioral changes by salmon and steelhead are based on qualitative assessments, not quantitative model results using EDT. Therefore, this memorandum acknowledges the uncertainty associated with the fish response to cool water releases in the Chehalis River and includes a qualitative assessment of potential fish behavioral responses.

Dam Operations

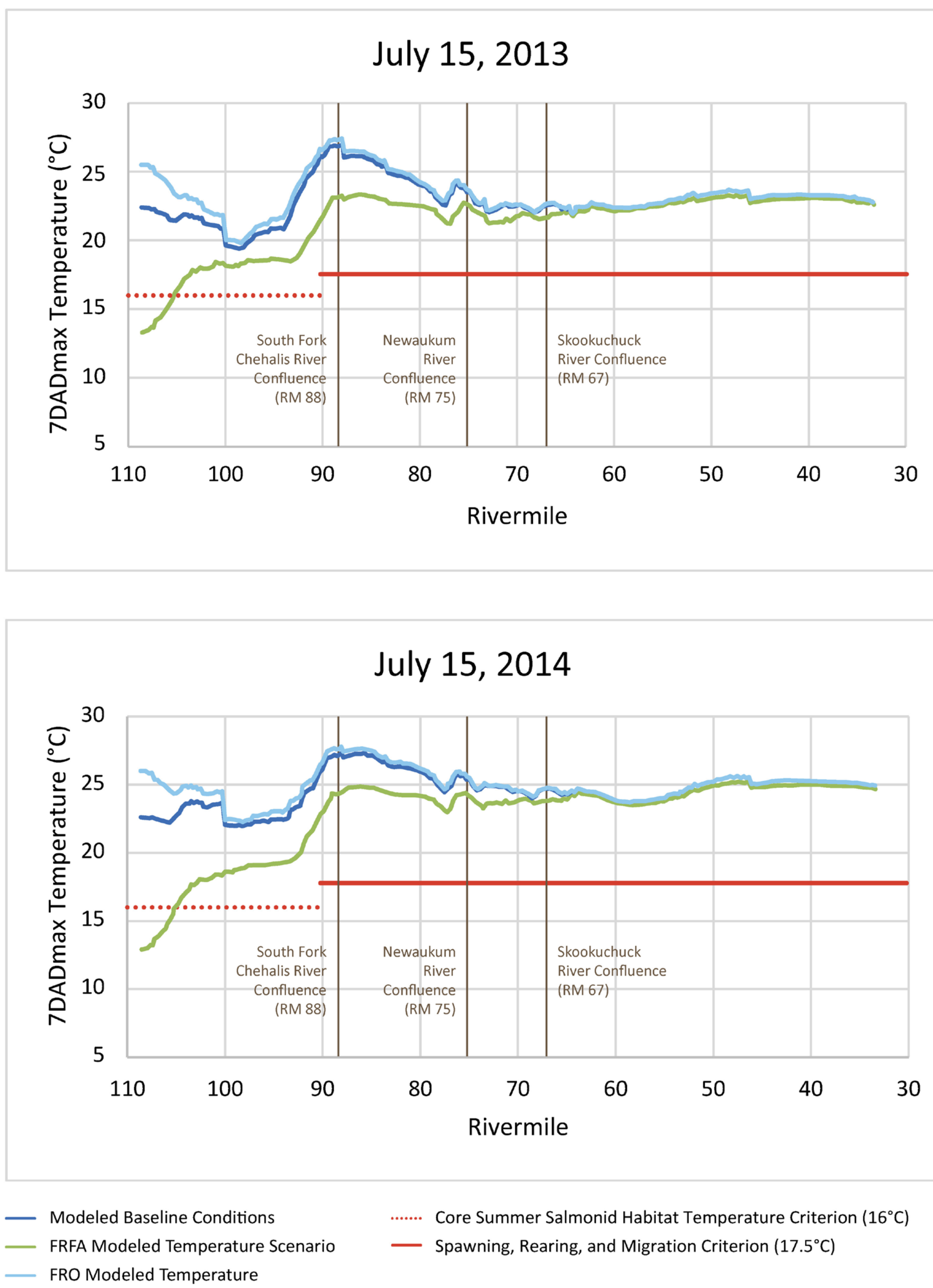
The primary purpose of an FRFA dam is to reduce flood damage during major floods along the Chehalis River floodplain. The secondary purpose is to augment flow and reduce water temperature in the mainstem Chehalis River downstream of the dam during low-flow periods in late spring through early fall. To serve both purposes, a reservoir would be constructed with a permanent pool of 65,000 acre-feet volume, and a flood pool above that level, with an additional 65,000 acre-feet volume to store floodwater. During spring through early fall months (May through September), water would be released from selected depths of the reservoir to maintain target flows and to reduce temperatures in the mainstem Chehalis River. Instream flow in the Chehalis River immediately downstream of the dam would be maintained at 150 cubic feet per second (cfs) in July and August, an increase of up to 130 cfs over existing low flows (see Figure 1).

Figure 1
Annual FRFA Minimum Releases Compared to Median Inflows



A reduction in water temperature in the mainstem Chehalis River would occur from approximately May through the first week of September, and the effect would extend approximately 33 miles below the dam to river mile (RM) 65. Temperatures would be reduced by as much as 10°C immediately downstream of the dam (see Figure 2) and attenuate moving downstream, resulting in small effects (less than 1°C) below RM 65 near the confluence with the Skookumchuck River (PSU 2016).

Figure 2
Modeled Temperatures Downstream of the Flood Retention Facility



Direct Observations

Temperature and Flow Modulation by Dams in Other Systems

Water temperature affects every aspect of the life of a fish, including incubation, growth, maturation, competition, migration, spawning, and resistance to parasites, diseases, and pollutants (Armour 1991). Salmonids require relatively cool water temperatures, and cool headwater areas are important holding and rearing areas for spring-run Chinook salmon across the Pacific Northwest. Spring-run Chinook salmon enter river systems earlier than they spawn and hold in the rivers during warm summer months, making them susceptible to water temperature during holding. For adult Chinook salmon, temperatures above 21°C) are considered a migration block and temperatures above 15.5°C during the pre-spawn holding period increase pre-spawn mortalities. This is due to disease and reduce subsequent survival of offspring to the eyed stage due to reduced egg quality (see an extensive review written for the U.S. Environmental Protection Agency [USEPA] of salmonid thermal tolerances by life stage in McCullough 1999). Modulating flow and temperature downstream of a dam to benefit salmon is not without precedent. Examples where cool water releases below dams are used to improve conditions for salmonids in other river systems include:

- Summer cool water releases from Shasta Dam in the Sacramento River, California, to provide suitable water temperatures for winter-run Chinook salmon that spawn below Keswick Dam during the summer and minimize mortality of adults during pre-spawning and spawning, as well as improve the survival of incubating eggs (NMFS 2009, 2016).
- Spring and early-summer cool water releases from Lewiston Dam in the Trinity River, California, to support protection of outmigrating smolts, protection of holding and spawning adults, and optimize juvenile salmonid growth for multiple species (USFWS and HVT 1999).
- Summer and early fall cool water releases from Willamette River, Oregon, dams to reduce pre-spawn mortality and reduce rate of egg development of multiple salmonid species (NMFS 2014)
- Summer cool water releases from Dworshak Dam in the Clearwater and Snake rivers, Idaho, to support adult salmonid upstream passage survival at lower Snake River dams that becomes thermally blocked during high summer water temperatures (NMFS 2014) and to support juvenile salmonid rearing and outmigration (FPC 2016).

Dams alter the magnitude, timing, and duration of flows downstream, and these alterations can shift seasonal water temperature regimes. In each of the examples presented previously, salmon and steelhead have benefitted from modifying dam operations subsequent to major declines in populations to augment flow or to reduce temperature at specific times of the year. For example, winter-run Chinook salmon in the Sacramento River were cut off from most of their original spawning grounds by Shasta Dam; the Evolutionary Significant Unit now persists (albeit listed as endangered by the National Marine Fisheries Service) partly because of agency-managed cool water releases from Shasta Reservoir and Keswick Dam during summer months (NMFS 2009, 2016). Lewiston Dam in the Trinity River, California, is an example of how a resource agency and tribe view the role of water temperature on salmonids below the dam (USFWS and HVT 1999), where adult Chinook salmon and steelhead immigrate to areas below Lewiston Dam in spring, summer, and fall to hold prior to spawning. To support these populations, the regional water quality control board, with assistance from regulatory agencies and the Hoopa Valley Tribe, established water temperature objectives for the first 40 miles below Lewiston Dam (CRWQCB-NCR 1994) based on water temperature requirements drawn from published literature (Boles 1988). Parallels can be drawn to a potential FRFA dam in the Chehalis River, as these cases depict responses of salmon to temperature modulation in river systems that are naturally warm during the summer, as occurs in the Chehalis River.

Temperature and Spring Chinook Salmon Distribution in the Chehalis River

Spring-run Chinook salmon in the Chehalis River enter the river in spring and reside within the system throughout the summer until they spawn in mid-September through mid-October (Ashcraft et al. 2016). During the period of pre-spawn holding, water temperatures in the Chehalis River often exceed temperature criteria established by USEPA, which can reduce performance and survival of holding adults (USEPA 2003). The weekly average temperatures between RM 108 (upstream of Pe Ell) and RM 75 (the Newaukum River) range from 20°C to 23°C in the warmest times of year, typically in July and August. Higher daily or hourly temperatures can occur. For example, daily maximum temperatures reached 27°C in July 2015 based on data collected by Washington Department of Fish and Wildlife (WDFW; Anchor QEA 2016). In addition, climate change is predicted to increase average annual air temperature in Washington from 4.3°C to 5.8°C by the middle of this century (Mauger et al. 2016), likely causing water temperature to increase further in the Chehalis River in the absence of habitat improvements.

High summer temperatures may limit the amount of suitable holding habitat available to spring-run Chinook salmon in the upper Chehalis River. Fish kill events during peak summer temperatures in the Chehalis River are a risk for spring-run Chinook salmon and have been observed in some years; for example, in the mainstem Chehalis River near the mouth of the Newaukum River in late July and early August 2009 (Kohn 2016). Summer temperatures may limit productivity of the spring-run Chinook salmon population in the upper Chehalis Basin and Basin-wide (GHLE 2011).

Spring-run Chinook salmon in the Chehalis River use diverse strategies and types of cool water refugia during the summer months. Surveys of adult Chehalis River spring-run Chinook salmon by the U.S. Geological Survey, WDFW, and the Confederated Tribes of the Chehalis Reservation in summer 2014 and 2015 showed that tagged and tracked adults survived the warm water temperatures by seeking cool water refugia early in the summer, then arresting their migration until just before spawning (Liedtke et al. 2016). Two tactics by spring-run Chinook salmon adults were observed:

- They held in areas with cooler water temperatures (including the South Fork Newaukum, the mainstem Chehalis River near the confluences with Cedar Creek or the Skookumchuck River, and in "Scheuber hole," a deep pool with stratified water)
- They moved to cooler tributaries early in the season before mainstem river temperatures rose to lethal levels

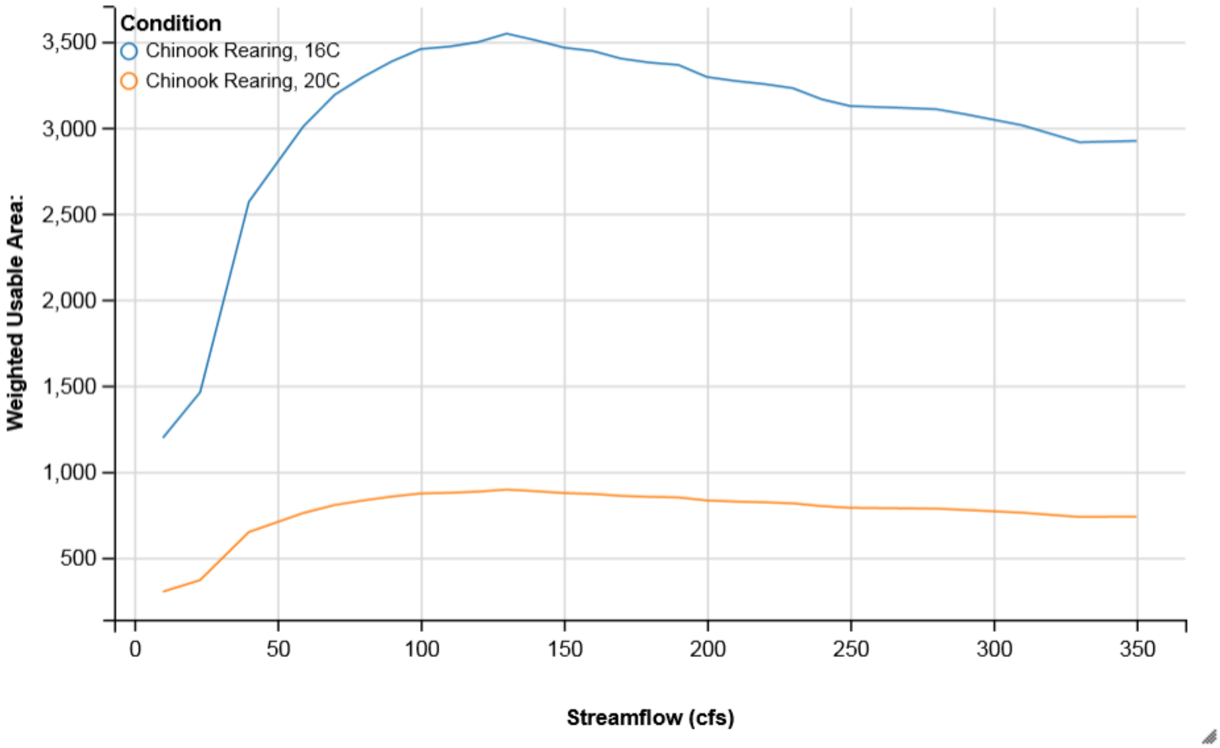
Liedtke et al. (2016) survey results suggest that the Chehalis River spring-run Chinook salmon population are behaviorally adapted to survive summers in this river, which is characterized by rain-dominant hydrology and warm summer temperatures.

Modeled Impact of Physical Changes with an FRFA Dam to Spring-run Chinook Salmon

In order to estimate the potential responses of spring-run Chinook salmon to the change in flow and temperature that would occur downstream of the FRFA dam, the effect on habitat area was modeled using the Physical Habitat Simulation (PHABSIM) and the effect on habitat productivity was modeled using EDT.

Analyses of available habitat for Chinook salmon in the Chehalis River were performed using a PHABSIM model of the upper Chehalis Basin. The PHABSIM model was prepared by Normandeau Associates in conjunction with WDFW to model relationships between flow and Weighted Usable Area (WUA), or the usable habitat in units of square feet per 1,000 feet of river channel (Normandeau 2012). Subsequently, the relationships between flow and WUA were modified to incorporate the effect of temperature on different life stages of salmon with input from WDFW (Beecher 2015). Figure 3 provides an example of the PHABSIM model output for the upper Chehalis River for the Chinook salmon rearing life stage (no WUA data are available for the pre-spawn adult holding life stage). At 20°C, a typical weekly average maximum for the mainstem upper Chehalis River, the usable habitat is small; at 16°C, the Core Summer Salmonid Habitat Temperature Criterion, the usable habitat increases substantially, illustrating the sensitivity of Chinook salmon to this range of temperatures. Not shown in Figure 3 is that modeled usable habitat at 25°C declines to zero.

Figure 3
Weighted Usable Area of Chinook Salmon Habitat by Streamflow and Temperature in the Upper Chehalis River



Previous habitat modeling using the EDT model indicates that temperature and flow modulation would likely increase the potential of habitat downstream of the dam to support spring-run Chinook salmon (ASEPTC 2014). This result was largely influenced by the assumption that the cool water releases would improve survival of adult spring-run Chinook salmon without addressing the uncertainty around behavioral adaptations and summer use of the reaches below the dam raised earlier in this memorandum. In an effort to update the parameters associated with the effects of the FRFA on salmonid habitat in the EDT model in 2016, a panel of biologists, geomorphologists, and restoration engineers working on the Chehalis Basin Strategy reviewed and rated the effects of the FRFA on 28 channel characteristics below the proposed dam, including maximum water temperature and flow (Tim Beechie, NMFS; Tim Abbe, Natural Systems Design; Larry Lestelle, Biostream Environmental; Willis "Chip" McConnaha, ICF International; and John Ferguson, Anchor QEA).

In this exercise, a total of five independent opinions were provided, and an improvement was defined as moving the habitat condition in a direction toward the historical condition of the Chehalis River. All participating panel members rated the FRFA as improving maximum water temperature for salmon. On a scale of 0 (no effect) to 4 (maximum effect), panel members' rankings of the effects of the dam on water temperature ranged from 1 to 3. Panel members generally rated the effect of the FRFA as an improvement to low flow (rankings ranged from 3 to 4); however, one member felt the FRFA would have a negative effect on low flow, meaning the dam would move habitat in a direction further away from the historical condition (ranking of -1). It should be noted that geomorphic changes caused by the dam could cause a moderate shift in channel structure and habitat types farther away from the historical condition downstream of the dam. These updated rankings and ratings were incorporated into the EDT model results for the Chehalis Basin Strategy Washington State Environmental Policy Act Programmatic Environmental Impact Statement (EIS).

To estimate a range of potential effects of the FRFA dam for preparation of the EIS, the EDT model was used to estimate changes in spring-run Chinook salmon habitat potential. This included the potential for the entire life cycle, from incubation, juvenile rearing, and adult holding and spawning, under alternative assumptions about flow and temperature conditions. Using EDT, the biological response of spring-run Chinook salmon is measured in terms of the productivity and capacity of the habitat, and reported as a change in numbers of fish that could be supported by the habitat at equilibrium. As noted previously, EDT is a habitat model where the fish response to temperature is constant. For fish to respond to the change in water temperature in the model, they would need to be physically present in the reach where temperature was modified by dam operations. To estimate the potential spring-run Chinook salmon responses to the FRFA dam, the change in salmon habitat potential with the change in flow and temperature above and below the proposed FRFA dam was modeled (see Table 1). This included the loss of stream reach productivity that would be inundated by the permanent reservoir and other changes in geomorphic habitat factors downstream of an FRFA dam that may affect the long-term survival of fish, including a coarsening of the substrate, a reduction in large wood, reduced bed scour, and changes in floodplain inundation during major floods or greater with the effects attenuating downstream (discussed in Section 4.2.2.2.2 of the EIS). The predicted change in spring-run Chinook salmon habitat potential to an FRFA dam is reported for groups or populations that originate from individual sub-basins of the Chehalis River, as well as for all Chehalis Basin spring-run Chinook salmon combined (see Table 1).

Table 1
Predicted Change in Spring-run Chinook Salmon Subpopulation Sizes With and Without Flow and Temperature Changes Downstream of a Proposed FRFA Dam

SUB-BASIN POPULATION	MODELED CURRENT HABITAT POTENTIAL FISH COUNT	MODELED CHANGE IN HABITAT POTENTIAL *WITH* FRFA FACILITY TEMPERATURE AND FLOW MODULATION FISH COUNT; PERCENT	QUALITATIVE ESTIMATE OF CHANGE IN HABITAT POTENTIAL *WITHOUT* FRFA FACILITY TEMPERATURE AND FLOW MODULATION[1] FISH COUNT; PERCENT
Mainstem Chehalis River from Skookumchuck to South Fork Chehalis Rivers, Skookumchuck River, Newaukum River, and Elk Creek Subpopulations	2,029	-35; -2%	-32; -2%
Mainstem Chehalis River from Elk Creek to Crim Creek	56	+38; +68%	-33; -59%
Upper Chehalis Basin above Crim Creek (above the Potential Dam)	61	-59; -97%	-59; -97%
All Populations Combined	**2,146**	**-57; -3%**	**-123; -6%**

Note:
1. To indirectly approximate the change in salmon populations without a response to flow and temperature modulation, the change in habitat potential downstream of the dam is estimated for a facility without temperature and flow modulation. The modeled impacts of the FRFA in the reservoir area upstream of the dam were combined with the modeled impacts of the flood retention only (FRO) facility downstream of the dam. The impacts downstream of an FRFA dam without flow and temperature modulation are estimated to be similar to the impacts of the FRO facility (FRO 100 scenario; see Section 4.2.4.2.1 in the EIS).

Modeling of habitat potential indicates that the summer flow increases and temperature reduction caused by an FRFA dam could improve habitat potential in the reach just below the dam to the confluence of Elk Creek, causing a localized increase in this sub-population of 67% (approximately 38 fish). However, habitat potential for spring-run Chinook salmon is predicted to be reduced downstream of Elk Creek and upstream of the dam, resulting in a total decline across all Chehalis Basin populations combined of -3% (approximately -57 fish; see Table 1).

To provide an alternative estimate that accounts for the uncertainty around spring-run Chinook responses to an FRFA facility, a qualitative approximation of the negative impacts that could occur if spring-run Chinook salmon do not respond to the changes in flow and temperature downstream of the FRFA dam is provided. EDT is a model of habitat and does not evaluate fish behavior; therefore, the range of behavioral responses to flow and temperature modulation cannot be evaluated directly using EDT. The potential change in salmon populations if spring-run Chinook do not respond to temperature and flow modulation was indirectly estimated by assuming downstream impacts would be similar to a scenario with no temperature or flow modulation, or similar to a flood retention only (FRO) facility. If there were no augmentation of flow and reduction in temperature below the dam, the habitat potential for the population spawning in the reach just below the dam would decline by approximately -59%, translating to a loss of approximately 33 fish. In total, the combined Chehalis Basin population would decline by -6% (approximately -123 fish) if no flow or temperature modulation were provided.

It should be noted that the predicted change in habitat potential does not account for climate change; impacts of the FRFA on spring-run Chinook salmon under future climatic conditions are included in the Climate Change section of the EIS.

Uncertainty Around Available Information

There are uncertainties associated with the conclusion that temperature limits the spring-run Chinook salmon population productivity in the Chehalis Basin. For instance, fish kills were not observed during summer 2015, which had atypically high temperatures and low water flows. The observed fish kills in the Chehalis River also point to inter-annual variability in the suitability of summer holding locations for spring-run Chinook salmon. The seasonal stability of cool water refuges and the availability of cool water refugia may vary depending on hydrologic conditions (Liedtke et al. 2016). Areas that are suitable for holding in some years may have lethal conditions in other years.

Spring-run Chinook salmon that currently spawn in the upper Chehalis River may hold over the summer elsewhere in the Chehalis Basin. Few adult spring-Chinook salmon have been observed using the upper Chehalis River for summer holding based on results of August snorkel surveys conducted in three consecutive years, 2013 to 2015 (Zimmerman and Winkowski 2016). This range of responses by spring-run Chinook salmon suggests that there is some behavior or local adaptation that has allowed them to maintain a sustainable and harvestable run by using other areas as refuge despite high water temperatures. Similar conclusions were drawn for spring-run Chinook salmon in the John Day River, which also supports spring-run Chinook salmon while reaching lethal temperatures in many areas of the basin during the summer months (Torgersen et al. 1999).

Flow and temperature are not the only habitat factors that affect salmon survival that could be changed downstream of an FRFA dam; other habitat factors that are predicted to change with the FRFA dam include retention of substrate upstream of the dam that could cause changes in spawning habitat and stream channel structure downstream of the dam (ASEPTC 2014).

In general, there is uncertainty around the actual physical changes in the river resulting from the dam, as well as the biological response of spring-run Chinook salmon to flow and temperature modulation below the dam. The potential behavioral response of spring-run Chinook salmon to the availability of cool water released from a dam in the upper Chehalis River is uncertain. If spring-run Chinook salmon continue to hold during the summer months elsewhere in the Chehalis Basin, there may be minimal to no response to cool water releases from an FRFA dam.

Conclusions

For salmonids, two potential responses to the changes in habitat that could occur with the physical outcomes of an FRFA dam are summarized as follows. In one case, increased modeled habitat potential results in an increase in population size. Alternatively, fish may continue to carry out adapted behaviors for the Chehalis River and would not respond to artificial temperature reductions and flow increases. If it is assumed that the population of spring-run Chinook salmon respond positively to reduced temperatures and increased flows resulting from flow augmentation and temperature reduction, the spring-run Chinook salmon population in the Chehalis Basin would decrease on the order of -3% with an FRFA dam, based on EDT model results. This decline is smaller than one based on a qualitative analysis where no benefits to spring-run Chinook salmon occur from flow and temperature modulation, which suggests the operation of the FRFA dam may result in a decline of 6% for the spring-run Chinook salmon population.

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