APPENDIX F
FISH POPULATION MODEL
CHEHALIS RIVER FISH STUDY

Prepared for
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1 INTRODUCTION

The Chehalis River Basin Flood Authority (Flood Authority) is evaluating the feasibility of reducing the frequency and severity of flooding on the Chehalis River by means of a flood retention structure on the upper mainstem Chehalis River at river mile (RM) 108.3. The evaluation includes consideration of two types of structures: 1) a flood storage only dam that would temporarily impound water in a reservoir during a high flow event for a more gradual release into the lower watershed, and 2) a multi-purpose dam that would provide the same flood capacity as the flood storage only dam, but would also continuously maintain a reservoir behind the dam in order to generate hydropower and would be operated to augment flows into the lower river over an extended time period.

The Flood Authority hired Anchor QEA to conduct a study to evaluate the potential effects of different flood retention structure options on fish populations in the mainstem Chehalis River between its headwaters near RM 126 and the town of Porter at RM 33. The scope of the fish study was originally developed as a 9-month analysis based largely on existing data. Although time extensions prolonged the study period, the scope of analysis remained the same. If planning for a dam continues, more comprehensive environmental assessment will be conducted.

The fish study focuses on three salmonid species—spring Chinook salmon, coho salmon, and winter steelhead. These species are commercially, recreationally, and culturally important. These species also use spatially diverse areas in the mainstem river and represent a diversity of anadromous life history strategies and habitat requirements. In order to assess the potential impacts on fish populations, the fish study included evaluations of hydrology and hydraulics, water quality, sediment transport, and fish habitat. The information provided by each of these evaluations was used in a fish population simulation model to estimate potential impacts to fish populations.

This appendix describes the fish population simulation modeling that was completed in support of the fish study. This fish population analysis applies the information gained in other aspects of the fish study to predict how salmon production in the river would change with the construction and operation of a dam.

2 UNDERSTANDING OF DAM STRUCTURE AND OPERATIONS

The investigation of the potential impacts to salmon in the mainstem Chehalis River entails characterizing existing conditions and predicting future conditions that are relevant to the quantity and quality of available salmonid habitat. The modeling effort required data inputs related to the proposed flood retention structure and its operation. Because some of the details related to the structure and its operation have not been determined, it was necessary to make assumptions to inform the modeling. As much as possible, the model assumptions were based on information on the flood retention structure that was provided in the EES Consulting report titled *Chehalis River Flood Water Retention Project Phase IIB Feasibility Study Review Draft* (2011). Table F-1 documents the Anchor QEA Team's understanding of the attributes of the Upper Chehalis mainstem flood retention structure that are relevant to the fish study, and related assumptions about the structure and its operations.

Table F-1

Assumptions Associated with the Proposed Chehalis River Water Storage Dam

Structural and Operational Element of Dam	Flood Storage Only Dam	Multi-Purpose Dam – Flood Storage, Hydropower, and Low Flow Augmentation
Watershed Area above Structure	68.8 square miles	68.8 square miles
Structure Height	238 feet	288 feet
Lowest Streambed Elevation at Structure Axis	432 feet	432 feet
Crest Elevation	670 feet	720 feet
Base Width	1,300 feet	1,600 feet
Reservoir Capacity	80,000 acre-feet for flood storage when reservoir filled to elevation 650 feet	145,000 acre-feet when reservoir filled to elevation 700 feet (80,000 acre-feet for flood storage and 65,000 acre-feet for hydropower generation)
Reservoir Surface Area	1,000 acres when reservoir filled to elevation 650 feet	1,450 acres when reservoir filled to elevation 700 feet
Maximum Water Depth during Flood Conditions	237.5 feet when reservoir filled to elevation 669.5 feet	287.5 feet when reservoir filled to elevation 719.5 feet
Reservoir Outlet Capacity	2,000 cubic feet per second (cfs)	2,000 cfs

Structural and Operational Element of Dam	Flood Storage Only Dam	Multi-Purpose Dam – Flood Storage, Hydropower, and Low Flow Augmentation
Reservoir Outlet Location	Release likely to be from base of reservoir	An intake tower or multiple outlets will be used to allow water to be released at varying depths depending on reservoir water surface elevation and desired temperature of releases
Flow Release Rate during Non-flood Conditions	Natural flows from upper watershed will pass through the reservoir reach and structure; no water impoundment during non-flood conditions	Based on average yearly conditions: 732 cfs between November 24 and March 31; 140 cfs between April 1 and November 23
Spillway Capacity	50,000 cfs when reservoir filled to elevation 669.5 feet	50,000 cfs when reservoir filled to elevation 719.5 feet
Upstream and Downstream Fish Passage	Fish passage will be provided	Fish passage will be provided
Sediment Transport from Upper Watershed	All coarse sediment load and some fraction of the fine sediment load (silt/clay) will be retained	All coarse sediment load and some fraction of the fine sediment load (silt/clay) will be retained
Large Woody Debris (LWD) Transport from Upper Watershed	Because the reservoir will be filled during peak flows when most large wood is transported, it is assumed that the structure does not allow LWD transport from the upper watershed	Because the reservoir will be maintained throughout the year, it is assumed that the structure does not allow LWD transport from the upper watershed

3 METHODS

3.1 Analytical Framework

The primary tool used in this fish population analysis is a habitat-based population simulation model using the SHIRAZ modeling platform. SHIRAZ is a spatially explicit life-cycle modeling platform that simulates the effects of environmental change on salmon populations (Battin et al. 2007). SHIRAZ uses a set of user-defined functional relationships among habitat characteristics, fish survival, and carrying capacity to evaluate population performance across space and time (Scheuerell et al. 2006). The model is used to translate the effects of changes to habitat quantity and quality resulting from a dam into consequences for salmonid population abundance and productivity in the basin. The mathematical basis of the SHIRAZ model is the Beverton-Holt stock recruitment model, which describes the relationship between spawners and the number of progeny (adults) that survive to return to the natal river (Beverton and Holt 1957). SHIRAZ is a Microsoft Excel-based modeling platform that provides easy access to all algorithms and allows the user to “build” the model. The model is developed by entering specific habitat and salmonid population data, as well as the “functional relationships” that characterize the relationship between habitat conditions and salmonid productivity.

The development of Chehalis River mainstem models to evaluate the potential salmonid population effects entailed three primary steps: 1) develop and calibrate a model to predict recent annual salmonid production; 2) modify the calibrated model to incorporate anticipated habitat changes resulting from the construction and operation of a dam; and 3) perform a sensitivity analysis to examine if “outlier” conditions (such as increased water temperatures) among habitat input parameters alter the trends among one or more of the salmonid populations.

The first step was to develop separate baseline models describing existing conditions for each of the three species. Calibration of each of these models entailed comparing empirical observations of fish abundance over multiple years.

The second step required modifying the baseline models to approximate the anticipated changes in habitat conditions that are likely to occur with the construction and operation of a dam. Separate scenarios were analyzed to investigate fish population impacts assuming different dam configurations and operation (i.e., flood storage only dam versus multi-purpose dam), as well as different fish passage survival rates past the dam (explained in Section 3.2.3.4). In addition, an optimization analysis was conducted for the multi-purpose dam scenario in which release flows from the reservoir were adjusted to provide maximum habitat area for the fish populations. The optimization analysis is explained further in Section 3.2.4.3. For each of the salmonid species analyzed, the following future alternatives were analyzed:

- Continuation of existing conditions (no dam)
- Flood storage only dam assuming target fish passage survival rates are achieved
- Flood storage only dam assuming poor fish passage survival rates are achieved
- Flood storage only dam assuming no fish passage survival is achieved
- Multi-purpose dam (flood storage, hydropower, and low-flow augmentation) assuming target fish passage survival rates are achieved
- Multi-purpose dam (flood storage, hydropower, and low-flow augmentation) assuming poor fish passage survival rates are achieved
- Multi-purpose dam (flood storage, hydropower, and low-flow augmentation) assuming no fish passage survival is achieved

The models were run assuming the dam was constructed in 2011. This dam construction year was chosen because it was the first year without empirical data, and starting the dam simulations in that year provided the greatest certainty for the starting conditions of the fish populations and habitat.

The third step was to test the sensitivity of model outputs to changes in habitat conditions from those conditions used to develop the baseline models. This sensitivity analysis also provided an important check of whether the fish population might be particularly vulnerable to conditions outside the assigned range of those habitat inputs used in developing the baseline models. The sensitivity analysis was conducted to examine changes in salmonid spawner abundance if less favorable habitat conditions occurred in the basin. The habitat parameters that were varied in the sensitivity analysis depended on which parameters are included in the model for each species.

3.2 SHIRAZ Input Components

SHIRAZ requires four primary data components in order to characterize the population being analyzed and the habitat conditions affecting the population's survival from one life stage to the next: 1) study area characteristics; 2) fish population data; 3) habitat capacity data; and 4) habitat productivity data. This section describes each of these components. Fish population, habitat capacity, and habitat productivity information is presented for existing conditions, followed by a description of any changes made to these data components for characterizing anticipated future conditions with the construction and operation of a dam.

3.2.1 Anticipated Habitat Changes Resulting from the Construction and Operation of a Dam

Several types of watershed changes are expected occur with the construction and operation of a dam. In some cases, the changes are the same with a flood storage only dam or a multi-purpose dam, while in other cases the changes differ depending on the type of dam. Table F-2 describes the watershed changes input to the models and the section number where the specific model inputs are made.

Table F-2

Model Input Adjustments in Dam Scenario Analysis

Type of Watershed Change	Dam Type Change Applies To		Report Section Describing Model Input Change
	Flood Storage Only Dam	Multi-Purpose Dam	
Decreased frequency and magnitude of high flow events	✓	✓	3.2.4.1
Decreased quantity of habitat available in the upper watershed	✓	✓	3.2.4.2.1, 3.2.4.2.2, 3.2.4.3.1, 3.2.4.3.2
Decreased habitat quantity to account for loss of sediment bedload and large wood	✓	✓	3.2.4.2, 3.2.4.3
Increased percent fine sediments in the downstream of the dam	✓	✓	3.2.5.2.1
Increased base flows in the lower river during periods of naturally low flow		✓	3.2.5.4.1
Altered water temperatures downstream of dam		✓	3.2.5.1.1, 3.2.5.3.1, 3.2.5.4.2

In addition to the watershed changes, fish population response is affected by the survival of fish passing the dam. Model inputs to characterize the survival of upstream migrating adult salmonids and downstream migrating juvenile salmonids are described in Section 2.2.3.4.

3.2.2 Study Area

The Chehalis River is located in the southwest part of Washington State (see Figure F-1) and in general runs in a south to north direction before heading west near Centralia, Washington. The river extends approximately 126 miles from its headwaters to its terminus in the Grays Harbor estuary. Spanning more than 2,660 square miles, the Chehalis River Basin is the second largest watershed in the state of Washington outside the Columbia River Basin.

The Chehalis River system is largely rain-fed with precipitation levels that range from 45 inches per year in the eastern Chehalis River valley to more than 200 inches per year in the Olympic Mountains. Agriculture, suburban, and urban land use dominate the floodplain and lowland areas of the river, and forests largely cover the higher elevations in the Cascade, Coast, and Olympic mountain ranges. In total, forests encompass approximately 85 percent of the watershed area. Agriculture comprises approximately 10 percent and urban/industrial uses comprise much of the remaining 5 percent (Pickett 1992).

The upper Chehalis River mainstem above the town of Pe Ell (RM 106) has a confined channel with a moderate to low gradient (Weyerhaueser 1994). The land use in this area is predominantly forestry (Smith and Wenger 2001). As the river flows downstream and approaches the confluence with the Newaukum River at RM 75.3, the floodplain broadens. Land use along the river banks between RM 106 and the Newaukum River is dominated by agriculture.

Just downstream of the Newaukum River are the cities of Chehalis and Centralia. This reach from RM 75.3 to RM 66.8, where the Skookumchuck River enters the Chehalis River, is very low gradient with a deeply cut channel and a streambed composed of sands. Land use in this area is urban and industrial. Downstream of the confluence with the Skookumchuck River, the land use surrounding the mainstem is dominated by agriculture, although some areas of dense residential development are present.

The study area for this modeling effort was the mainstem Chehalis River from RM 33 upstream to the headwaters of the East and West Fork of the Chehalis River (see Figure F-1). This area would be directly affected by the proposed flood storage facility. The study area was divided into seven reaches based on proximity to the proposed dam site, channel size, and hydrology:

- Upper watershed above the proposed dam site on the upper Chehalis River (mainstem and tributaries upstream of RM 108.3)
- Proposed dam site on the upper Chehalis River to Elk Creek (RM 108.3 to RM 100.2)
- Elk Creek to South Fork Chehalis (RM 100.2 to RM 88.0)
- South Fork Chehalis to Newaukum River (RM 88.0 to RM 75.3)
- Newaukum River to Skookumchuck River (RM 75.3 to RM 66.8)
- Skookumchuck River to Black River (RM 66.8 to RM 47.0)
- Black River to Porter (RM 47.0 to RM 33.3)

SHIRAZ tracks fish populations during their freshwater residence and seaward migration within each reach. All areas downstream of Porter, including the estuary and ocean, were collectively considered to be one "reach" because of the large spatial scales over which fish use them and limited survival data with which to parameterize the model (Scheuerell et al. 2006).

3.2.3 Fish Population Data

3.2.3.1 Life History

Life histories of the Chehalis River salmonids being analyzed were assembled from the published literature (Williams et al. 1975; WDF et al. 1993; WDFW 2002; Light and Herger 1994) and through meetings and discussions with Washington Department of Fish and Wildlife (WDFW) staff, primarily at the Montesano regional office. Figure F-2 summarizes the timing and life history of each of these species.

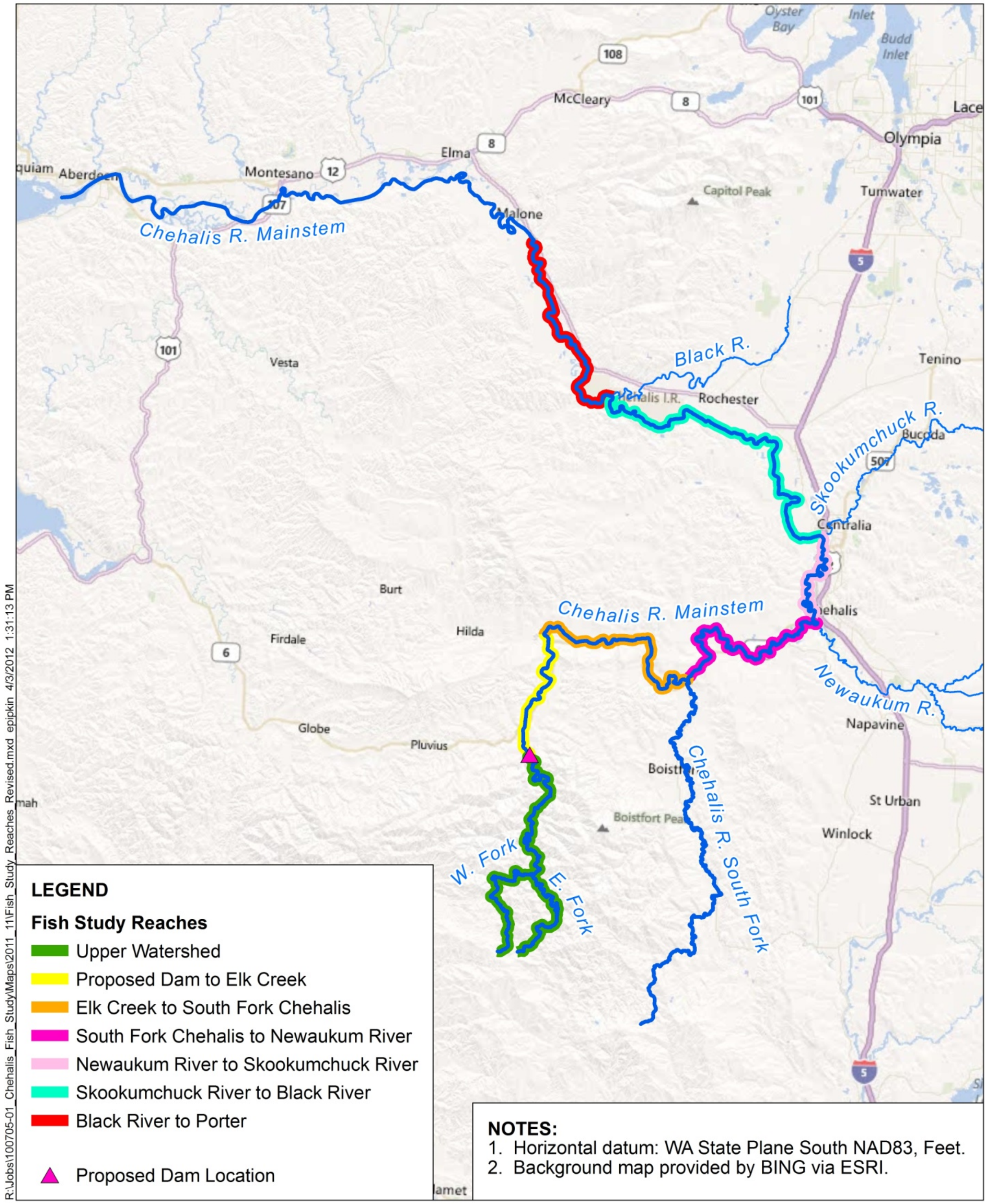
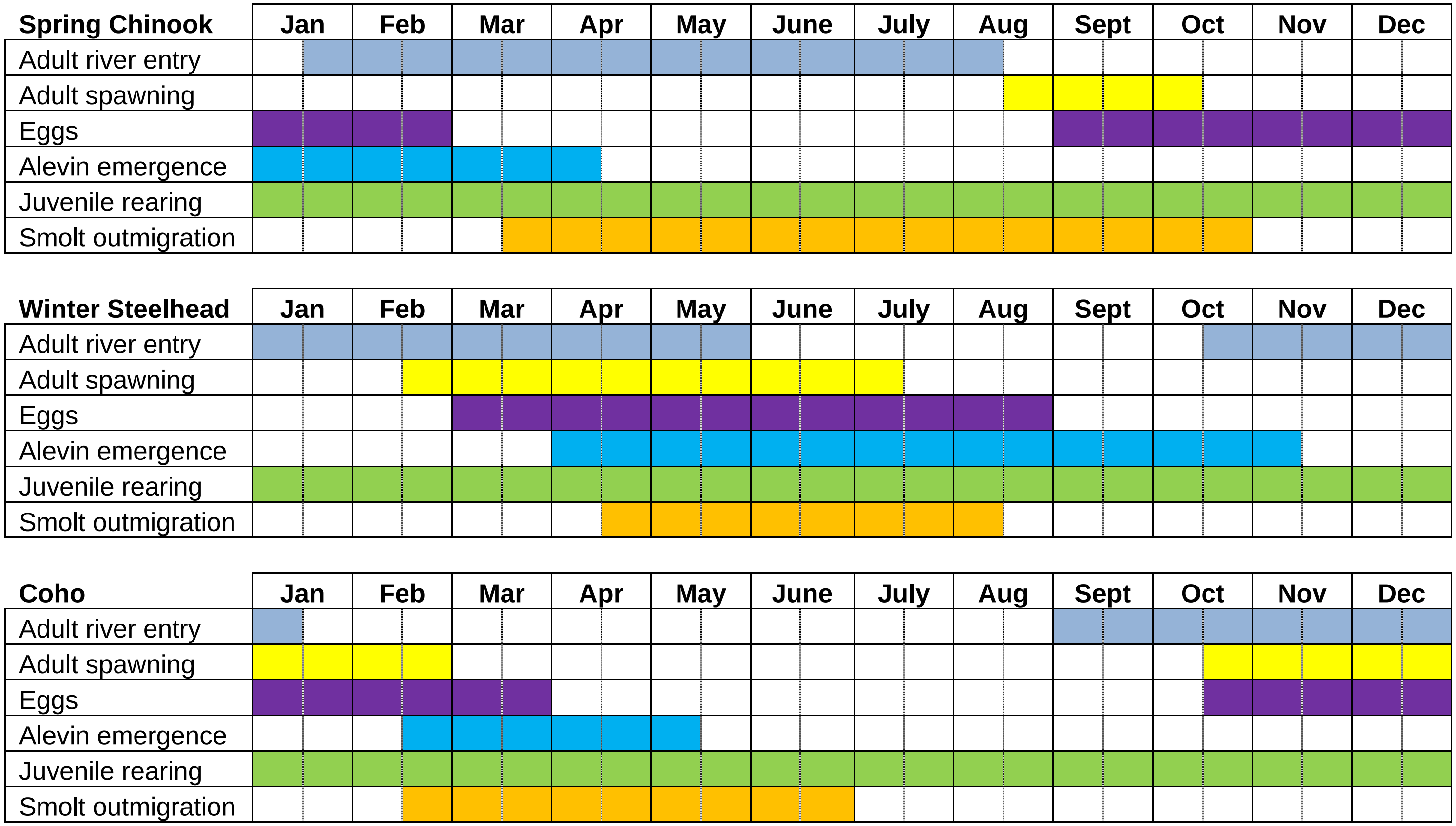


Figure F-1

Assessment Reaches Used in Fish Study Analysis



Spring Chinook	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
Adult river entry		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦									
Adult spawning																🟨	🟨	🟨	🟨					
Eggs	🟪	🟪	🟪	🟪													🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
Alevin emergence	🟦	🟦	🟦	🟦	🟦	🟦	🟦																	
Juvenile rearing	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Smolt outmigration						🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧				

Winter Steelhead	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
Adult river entry	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦										🟦	🟦	🟦	🟦	🟦
Adult spawning				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨											
Eggs					🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪								
Alevin emergence							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			
Juvenile rearing	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Smolt outmigration								🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧									

Coho	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
Adult river entry	🟦																🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Adult spawning	🟨	🟨	🟨	🟨																🟨	🟨	🟨	🟨	🟨
Eggs	🟪	🟪	🟪	🟪	🟪	🟪														🟪	🟪	🟪	🟪	🟪
Alevin emergence				🟦	🟦	🟦	🟦	🟦	🟦															
Juvenile rearing	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Smolt outmigration				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧												

Figure F-2

Freshwater Life Stages of Chehalis River Spring Chinook Salmon, Winter Steelhead, and Coho Salmon

3.2.3.1.1 Spring Chinook

Adult spring Chinook salmon enter the Chehalis River in late January to early February (WDFW 2002). These fish hold in the river until spawning begins in late August to mid-October, peaking in late September. Eggs develop in the gravels from September through February, and fry start to emerge from the gravels in January. Best available information indicates that spring Chinook salmon outmigrate from the Chehalis River predominantly as underyearlings with relatively few yearling smolts. Data from the Quinault Fisheries Department (1995), as cited in Myers et al. (1998), indicate that approximately 96 percent of the spring Chinook salmon outmigrate before their first winter in freshwater. Of those outmigrating as underyearlings, data from the Skagit River were used to estimate the percentage that outmigrate in the spring as fry and the percentage that outmigrate as parr in the summer or early fall. Based on the Skagit River information from Beamer (pers. comm., 2011), it was estimated that 72 percent of all spring Chinook salmon in the river outmigrate as fry and 24 percent outmigrate as parr. Data from WDFW on the age-at-return of spring Chinook in the Chehalis River basin indicate that 2 percent return at age 1 (i.e., after one winter in the ocean), 16 percent return at age 2, 58 percent return at age 3, and 24 percent return at age 4.

3.2.3.1.2 Winter Steelhead

Adult winter steelhead enter the Chehalis River in mid-October to mid-April (Williams et al. 1975). They hold in the river until spawning begins in mid-February to mid-July (WDFW 2002). Eggs develop in the gravels from March through September. Fry start to emerge from the gravels in June and freshwater rearing ranges from 1 to 3 years (NMFS 1996). Winter steelhead outmigrate from the Chehalis River at ages 1+, 2+, and 3+. NMFS (1996) reports that 10 percent outmigrate at age 1+, 88 percent outmigrate at age 2+, and 2 percent outmigrate at age 3+. Adult winter steelhead return after 1 to 4 years in the ocean in the following distribution: 7 percent return at age 1, 72 percent return at age 2, 20 percent return at age 3, and 1 percent return at age 4 (NMFS 1996).

3.2.3.1.3 Coho

Adult coho salmon enter the Chehalis River in mid-September to mid-January (Williams et al. 1975). They hold in the river until spawning begins in mid-October to the end of

February. Eggs develop in the gravels from mid-October through mid-April. Fry emerge from the gravels beginning in mid-February and rear an additional year before heading out to sea between mid-February and mid-June as smolts (WDFW 2008). Smolts mature in the ocean and return as adults approximately 18 months later.

3.2.3.1.4 Fish Stocks and Life History in the SHIRAZ Model

The SHIRAZ modeling assigns fish to specific life history trajectories. The juvenile spring Chinook salmon population was divided into three different outmigration trajectories: 1) fry outmigrants that outmigrate in the spring of their first year (age 0+); 2) parr outmigrants that outmigrate in the summer and early fall of their first year (age 0+); and 3) yearling outmigrants that overwinter in the river and outmigrate in June of their second year (age 1+). Winter steelhead have three outmigration trajectories based on whether they outmigrate at age 1+, 2+, or 3+. Coho salmon consist of a single outmigration trajectory because all coho salmon outmigrate at age 1+.

Table F-3

Model Inputs for Age of Smolt Outmigration and Age of Return as Adults

	Age	Spring Chinook	Winter Steelhead	Coho
Juvenile Outmigration Age	Subyearlings (age 0+) in first spring	72%	0%	0%
	Subyearlings (age 0+) in first summer	24%	0%	0%
	Yearlings (age 1+) in second spring	4%	10%	100%
	Age 2+ in third spring	0%	88%	0%
	Age 3+ in fourth spring	0%	2%	0%
Adult Return Age	Ocean Age 1	2%	7%	100%
	Ocean Age 2	16%	72%	0%
	Ocean Age 3	58%	20%	0%
	Ocean Age 4	24%	1%	0%

3.2.3.2 Spatial Distribution for Spawning

3.2.3.2.1 Chehalis River Spawning Distribution Estimates

WDFW and the Quinault Indian Nation conduct annual spawning ground surveys for spring Chinook salmon, winter steelhead, and coho salmon in the Chehalis River Basin. For the three species, WDFW provided a summary spreadsheet documenting the escapement estimate for between 10 to 20 years from the early 1990s through 2010. The distribution of spawners by study reach is presented in Table F-4. Ninety-one percent of observed winter steelhead and coho salmon redds were upstream of the proposed dam site, and all observed redds were upstream of the South Fork Chehalis River. Only 6 percent of observed spring Chinook salmon redds were upriver of the proposed dam site. By reach, the highest percent of observed spring Chinook salmon redds were in the Elk Creek to South Fork Chehalis River (34 percent), Proposed Dam Site to Elk Creek (27 percent), and Skookumchuck River to Black River (20 percent) reaches.

Table F-4

Spawning Distributions of Salmonids by Study Reach

Reach	Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	6%	91%	91%
Proposed Dam Site to Elk Creek	27%	7%	9%
Elk Creek to South Fork Chehalis	34%	2%	0%
South Fork Chehalis to Newaukum River	11%	0%	0%
Newaukum River to Skookumchuck River	0%	0%	0%
Skookumchuck River to Black River	20%	0%	0%
Black River to Porter	2%	0%	0%

3.2.3.2.2 Stray Rates

Although salmon are known for the fact that they return to their natal rivers after the ocean phase of their life (called "homing"), a portion of returning adults "stray" by returning to rivers other than their natal river. Sometimes straying is to other tributaries within a large river system (e.g., Satsop-River-origin fish returning to the South Fork Chehalis River), and in other instances it is fish returning to completely different river systems (e.g., Chehalis-River-origin fish returning to the Queets River). At the population scale, straying is understood to be an important mechanism for salmonids to maintain spatial diversity and prevent a localized catastrophe from completely eliminating a population. Straying also leads to salmonid colonization of new habitats. In a compilation of stray rates from one tributary to another area within a large river system, Hendry and Stearns (2004) reported highly variable stray rates among salmonid populations and between species ranging from less than 1 percent to greater than 40 percent. Quinn (1997) provided a rough estimate of 90 percent plus or minus 10 percent home, meaning between 0 and 20 percent naturally stray.

In this analysis of potential dam impacts, adult straying is an important fish response to consider because it is an indicator of each population's ability to respond to partial blockage of its normal spawning habitat in the upper portions of the watershed. Empirical data characterizing salmonid stray rates before and after the construction of a dam were not identified. However, the eruption of Mount St. Helens in 1980 made the Toutle River unsuitable due to extensive mud and debris flows. In this way, the volcanic eruption blocked fish access to upriver habitat in a manner similar to the obstruction that would be posed by a dam without fish passage. Following the eruption, Leider (1989) documented increased straying by adult steelhead, reporting stray rates of 16 percent in the lower portions of the nearest upstream river before the eruption and 45 percent following the eruption. These data suggest that upon encountering a blockage in the Toutle River, steelhead may have altered their migration pattern and strayed to nearby accessible areas.

For the purposes of this study, an assumed stray rate of 20 percent among assessment reaches was assumed. This is the upper end of the stray rates described in Quinn (1997), near the midpoint of stray rates reported by Hendry and Stearns (2004), and comparable to pre-eruption rates reported by Leider (1989). The stray rates were applied by assigning the percentage of adult spawners returning to each reach. Stray rates were calculated only for those reaches in which the spawning distribution identified in Table F-5 was greater than 0 percent. In addition, the portion of the 20 percent spawners assigned to each reach was based on the Table-F-5 spawning distributions. In this way, strays were assigned to the reaches where spawner observation data indicate that more fish spawn. The model applies the stray rates to the spawning distribution inputs presented in Table F-5.

Table F-5
Percentage of Freshwater Residence Time Spent in Each Reach Depending on Reach of Origin for the Juvenile Salmonids

		Reach where Juvenile Salmonids Emerged						
Percentage of Total Freshwater Residence Time Spent in Each Reach	**Reach**	**Black River to Porter**	**Skookumchuck River to Black River**	**Newaukum River to Skookumchuck River**	**South Fork Chehalis to Newaukum River**	**Elk Creek to South Fork Chehalis**	**Proposed Dam Site to Elk Creek**	**Upper Watershed to Proposed Dam Site**
	Black River to Porter	100.0%	50.0%	25.0%	25.0%	16.6%	12.5%	10.0%
	Skookumchuck River to Black River		50.0%	25.0%	25.0%	16.7%	12.5%	10.0%
	Newaukum River to Skookumchuck River			50.0%	0%	0%	0%	0%
	South Fork Chehalis to Newaukum River				50.0%	16.7%	12.5%	10.0%
	Elk Creek to South Fork Chehalis					50.0%	12.5%	10.0%
	Proposed Dam Site to Elk Creek						50.0%	10.0%
	Upper Watershed to Proposed Dam Site							50.0%

3.2.3.3 Spatial Distribution for Rearing

Data on juvenile salmonid rearing distributions along the mainstem study area were not available. WDFW staff stated that few if any juvenile salmonids rear in the lower river during the summer months when temperatures are high. Initial rearing locations among the study reaches were entered into the model based on where spawning occurred. The spatial distributions for juvenile salmon of each species are characterized in Table F-5, as the percent of rearing time in each assessment reach. The percentages were assigned based on the reach where juvenile salmonids emerged. In the table, the percentages in each column add up to 100 percent as they represent the percentage of time a fish originating in the reach identified in the column header spends in each reach. Juvenile salmonids were assumed to rear for 50 percent of the time in the reach they emerge. The remaining rearing period was evenly distributed among all downstream reaches, excluding the Newaukum River to Skookumchuck River reach. It was assumed that, due to high temperatures, fish migrate rapidly through the Newaukum River to Skookumchuck River reach. For example, fish rearing in the Proposed Dam Site to Elk Creek reach will spend 50 percent of their residence time in that reach and 12.5 percent in each of the downstream reaches except the Newaukum River to Skookumchuck River reach. The empty cells in the table are assigned to all reaches upstream of where juvenile salmonids emerge. In this way, the model allows for upstream movements within a reach, but not upstream into a different reach. This is a SHIRAZ limitation that required rearing time assignments that differed from the undocumented but assumed potential movement of juvenile salmon upstream into other reaches (Burkle, pers. comm., 2011).

3.2.3.4 Salmonid Survival Past Dam

The construction and operation of a dam poses challenges for upstream migrating adults salmonids and downstream migrating juvenile salmonids. The continuously maintained reservoir associated with the multi-purpose dam would provide additional survival challenges. For the purposes of this study, it has been assumed that fish passage would be provided for upstream and downstream migrating fish. Given that either dam would be higher than 200 feet, it is expected that fish passage would be provided by trap and haul operations. The term “trap and haul” refers to the collection of fish at one side of the dam, transport via truck to the other side of the dam, and release back to the river.

Fish passage at dams can be a very challenging proposition. Depending on the type of fish passage system in use, direct mortality can occur at the dam, in the reservoir as fish move from a stream to a “lake” setting, during transport, and near the release location. Indirect mortality can also occur as a result of fish passage delays or reduced fitness related to stress, disease, predation, high temperatures, or altered foraging opportunities. Survival rates past dams are highly variable, and in general, survival for juvenile salmonid outmigrants tends to be lower and more variable than for adults. The Columbia River system is an exception to this general statement, as relatively high percentages of juvenile salmonids survive each of the mainstem dams encountered during their outmigration. For example, Faulkner et al. (2009, 2010) reported juvenile yearling Chinook and steelhead survival past a single dam (from one reservoir to the next downstream reservoir) ranging from 85 to 100 percent and from 78 to 98 percent, respectively, for a series of mainstem Columbia River dams. Studies on the Cowlitz River provide examples of lower survival rates, despite continued efforts to maximize juvenile fish passage survival. Over a 10-year period at the Cowlitz Falls dam facility, survival of juvenile Chinook salmon averaged 23 percent (range of 13 to 39 percent), steelhead survival averaged 49 percent (range of 27 to 68 percent), and coho salmon survival averaged 32 percent (range of 15 to 56 percent) (Serl and Morrill 2009; Unattributed 2008; Serl and Heimbigner 2011; and Serl and Heimbigner unpubl. data).

Adult fish passage survival is typically high. Pratt and Chapman (1989) concluded that 5 percent mortality per dam in the Columbia River was a reasonable estimate for steelhead based on a review of available data. More recently, Cramer and Beamesderfer (2006) applied the same rate in a life history modeling analysis.

For the purposes of this study, model scenarios were run with three fish passage survival rates. The benchmark survival rates used are 80 percent for juveniles and 95 percent for adults. These survival rates are on the order of target survival rates that resource agencies could be expected to require. The juvenile rate of 80 percent survival was assigned based on the range of survival rates reported by Faulkner et al. (2009, 2010) with an additional reduction of 10 percent based on reduced survival through the reservoir inundation area. Adult fish passage survival in this scenario was assumed to be 95 percent, which is consistent with fish passage survival observed in the Columbia River watershed.

Because of the uncertainty in achieving such survival rates, two other fish passage survival rate scenarios were modeled. A "poor" fish passage survival scenario run was a reduced survival scenario using the average observed juvenile survival rates from the Cowlitz Falls facility. In this scenario, juvenile survival rates were assumed to be 23 percent among spring Chinook salmon, 49 percent among winter steelhead, and 32 percent among coho salmon. Adult survival rates were assumed to be 80 percent. The third scenario that was run assumed failure of fish passage efforts and a 0 percent upstream and downstream fish passage survival rate. This run with no fish passage survival provides an estimate of fish population impacts in a worst-case fish passage survival scenario.

3.2.4 Habitat Capacity Model Inputs

The carrying capacity of an aquatic ecosystem is a fundamental component of the Beverton-Holt (1957) model upon which the SHIRAZ model is built. Carrying capacity coupled with habitat productivity determines how many individuals survive to the next life stage. This fish study included an intensive habitat mapping effort on the mainstem from the proposed dam site downstream to Porter. Physical Habitat Simulation (PHABSIM) techniques were used in the study as reported in Appendix D of the main report. The PHABSIM analysis estimates the amount of habitat (quantified as Weighted Usable Area [WUA] and reported in square feet (feet^2) of habitat available per 1,000 feet of river length) available to different life stages at different river flows based on the fishes' preferences for water depth, velocity, substrate, and cover. The estimate of WUA was calculated separately for each study reach below the dam.

The amounts of available habitat in the study reaches downstream of the proposed dam site were estimated using the PHABSIM results. Separate estimates were prepared for each life stage and depended on the flow conditions during the time period that the life stage was present. In each of the following sub-sections describing habitat capacity inputs, the time periods applied in the analysis are presented. These time periods represent the general peak time of the life stage, rather than the more inclusive time period described in the life history section (3.2.3.1). This approach was taken so that model inputs best represented the habitat conditions experienced by most of the fish in a given life stage.

Habitat in the upper watershed above the proposed dam site was estimated using the Habitat Evaluation Procedure (HEP) developed by the U.S. Fish and Wildlife Service (USFWS) (1980) for quantifying available habitat using Habitat Suitability Indices and total area of habitat. The HEP approach was used for this estimate rather than PHABSIM because the upper watershed reach could only be surveyed during one event and PHABSIM requires three survey events. The HEP inventory included mainstem and tributary survey sections and the findings are reported in Appendix E of the main report. The HEP inventory estimated the amount of habitat area available for the different species and life stages in each section of the river surveyed. As described in Appendix E, these section results were extrapolated to the entire anadromous fish zone to provide overall estimates of habitat area above the proposed dam site.

The amounts of available habitat used as model inputs were modified based on the fish use data described in sections 3.2.3.2 and 3.2.3.3. If existing information indicates that a life stage does not use a specific reach, then the habitat area model input for that reach was reduced to 0. For example, because no coho salmon spawning has been documented in the Black River to Porter Reach, the model input for coho salmon spawning habitat in that reach was 0. This approach was taken to ensure that the model did not distribute fish to reaches where they have not been observed.

3.2.4.1 Existing Conditions

3.2.4.1.1 Spawning Area

The PHABSIM study provided separated WUA curves for spring Chinook salmon, winter steelhead, and coho salmon spawners to characterize the quantity of habitat available based on the amount of river flow. WUA curves were calculated for each reach.

The first step in estimating the quantity of spawning habitat in each PHABSIM reach (i.e., all reaches below the dam) and for each species was to identify the mean flow over the spawning period. The spawning periods used in this analysis were:

- Spring Chinook salmon – August 16 through October 15
- Winter steelhead – March 1 through May 30
- Coho salmon – November 1 through January 31

The mean flow was determined based on flow data from the U.S. Geological Survey gages at Doty (No. 12020000), Grand Mound (No. 12027500), and Porter (No. 12031000). The flows are based on statistical analyses from the hydrologic analysis (see main report Appendix A). The analysis used data from water years 1989 through 2010 (October 1, 1988, through September 30, 2010). The Doty gage flows were applied to the four reaches upstream of the Newaukum River. The Grand Mound gage flows were applied to the two reaches between the Newaukum River and the Black River. The Porter gage flows were applied to the Black River to Porter reach.

Next, the appropriate WUA estimate corresponding to the flow was identified. In order to estimate habitat over the entire study reach, the WUA amount, which was provided in feet^2 per 1,000 feet of river length, was extrapolated to the entire length of the study reach. The final step in estimating available habitat in each reach was to convert the units to metric.

The quantity of spawning habitat in the Upper Watershed to Proposed Dam Site reach was estimated in the HEP survey (see main report Appendix E). The calculated spawning areas in each reach and for each species are presented in Table F-6.

Table F-6

Average River Flows and Estimated Spawning Area in Existing Conditions Analysis

	Average Flow During Spawning Period (cfs)			Spawning Area (m^2)		
Reach	**Spring Chinook**	**Winter Steelhead**	**Coho**	**Spring Chinook**	**Winter Steelhead**	**Coho**
Upper Watershed to Proposed Dam Site	40	416	760	97,035	229,519	226,682
Proposed Dam Site to Elk Creek	40	416	760	22,596	63,318	40,966
Elk Creek to South Fork Chehalis	40	416	760	5,408	89,914	0
South Fork Chehalis to Newaukum River	40	416	760	500	0	0
Newaukum River to Skookumchuck River	293	2,227	3,785	0	0	0
Skookumchuck River to Black River	293	2,227	3,785	161,705	0	0
Black River to Porter	440	3,385	5,518	212,793	0	0

3.2.4.1.2 Rearing Area

The PHABSIM study provided separate WUA curves for spring Chinook salmon, winter steelhead, and coho salmon juveniles that were used to estimate the quantity of habitat available based on the level of river flow. WUA curves were calculated for each reach. Separate flow estimates were prepared for spring rearing (March 1 through June 30), summer rearing (July 1 through September 30), and overwinter rearing (October 1 through February 28). Flow estimates were calculated as the mean flow during each rearing period.

The first step in estimating the quantity of rearing habitat in each PHABSIM reach (i.e., all reaches below the dam) and for each species was to identify the mean flow over the rearing period. The amount of rearing habitat for juvenile coho salmon was estimated using the PHABSIM results for winter steelhead. Flow estimates were calculated as the mean flow during each rearing period.

Next, the appropriate WUA estimate corresponding to the flow was identified. In order to estimate habitat over the entire study reach, the WUA amount, which is provided in feet^2 per 1,000 feet of river length, was extrapolated to the entire length of the study reach. The final step in estimating available habitat in each reach was to convert to metric units. This step required converting extrapolated WUA outputs from feet^2 to square meters (m^2).

The quantity of rearing habitat in the Upper Watershed to Proposed Dam Site reach was estimated in the HEP survey (see main report Appendix E).

To estimate overwinter rearing area, the PHABSIM and HEP data were adjusted based on the availability of overwinter cover. Overwinter rearing area was limited to those portions of the assessment reaches that are composed of pools with cobble substrate. The PHABSIM habitat mapping data were used to identify the percent of the reach length that was composed of pools where the primary substrate is cobble or larger. In the Upper Watershed Reach, HEP data on winter habitat were used to identify the percentage of the total reach length with cobble substrate. The percentages identified for all assessment reaches were multiplied by the rearing area calculated using the PHABSIM and HEP data to arrive at an estimate of overwinter habitat area for each species by reach. The percent of reach length providing suitable overwinter habitat is presented in Table F-7.

Table F-7
Percentage of Reach Length Providing Overwinter Habitat for Salmonids Under Existing Conditions

Reach	Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	50%	54%	22%
Proposed Dam Site to Elk Creek	5%	5%	5%
Elk Creek to South Fork Chehalis	3%	3%	3%
South Fork Chehalis to Newaukum River	4%	4%	4%
Newaukum River to Skookumchuck River	0%	0%	0%
Skookumchuck River to Black River	1%	1%	1%
Black River to Porter	1%	1%	1%

The rearing area calculations, including the average flows used in the analysis, for spring rearing, summer rearing, and overwinter rearing are shown in Tables F-8, F-9, and F-10.

Table F-8
Average River Flows and Estimated Spring Rearing Area in Existing Conditions Analysis

Reach	Average River Flow During Spring Rearing Period (cfs)	Spring Rearing Area (m^2)		
		Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	343	124,176	284,714	98,923
Proposed Dam Site to Elk Creek	343	44,663	50,110	50,110
Elk Creek to South Fork Chehalis	343	113,501	110,978	110,978
South Fork Chehalis to Newaukum River	343	125,174	108,305	108,305
Newaukum River to Skookumchuck River	1,864	0	0	0
Skookumchuck River to Black River	1,864	353,383	330,289	330,289
Black River to Porter	2,816	73,852	63,646	63,646

Table F-9
Average River Flows and Estimated Summer Rearing Area in Existing Conditions Analysis

Reach	Average River Flow During Summer Rearing Period (cfs)	Summer Rearing Area (m^2)		
		Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	41	124,176	284,714	98,923
Proposed Dam Site to Elk Creek	41	23,632	20,002	20,002
Elk Creek to South Fork Chehalis	41	37,711	27,734	27,734
South Fork Chehalis to Newaukum River	41	50,000	30,000	30,000
Newaukum River to Skookumchuck River	290	0	0	0
Skookumchuck River to Black River	290	371,014	262,336	262,336
Black River to Porter	459	136,154	112,904	112,904

Table F-10
Average River Flows and Estimated Overwinter Rearing Area in Existing Conditions Analysis

Reach	Average River Flow During Overwinter Rearing Period (cfs)	Overwinter Rearing Area (m^2)		
		Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	601	62,088	62,637	21,763
Proposed Dam Site to Elk Creek	601	1,562	1,742	1,742
Elk Creek to South Fork Chehalis	601	2,969	3,021	3,021
South Fork Chehalis to Newaukum River	601	5,111	4,801	4,801
Newaukum River to Skookumchuck River	3,785	0	0	0
Skookumchuck River to Black River	3,785	2,001	1,996	1,996
Black River to Porter	5,518	751	605	605

3.2.4.2 Habitat Capacity Inputs for a Flood Storage Only Dam Scenario

The construction and operation of a flood storage only dam would alter the availability of suitable habitat for each life stage through changes in flow rates during high-flow events, as well as changes in bedload transport and other natural processes. To account for these flow rate changes, estimated future flow rates with a flood control dam were applied to the PHABSIM results to calculate habitat area. The PHABSIM results were adjusted in the two reaches just downstream of the proposed dam site to account for the expected geomorphologic changes (Appendix B), including the additional deposition of finer grained (i.e., sand) bedload would be expected in the reaches upstream of the confluence with the South Fork Chehalis River. As described in Section 3.2.4.1 on existing conditions, the quantity of habitat was calculated for each species and life stage using the PHABSIM (with adjusted substrate conditions) and HEP results.

Another difference in model inputs for habitat area between the flood storage only dam and existing conditions scenario was applied to account for the interruption of sediment bedload and large woody debris transport from the upper watershed to reaches below the dam, as well as the reduction in higher channel maintenance flows. These interruptions to natural river processes were accounted for in the model through the use of a habitat decay factor that was applied to all reaches downstream of the proposed dam site. The habitat decay factor was established to reduce the amount of habitat by 0.5 percent per year, so that by the end of the 50-year simulation period, the available habitat below the dam was approximately 75 percent of the amount estimated in the existing conditions scenario. In this way, the habitat area numbers presented represent the year-1 conditions and will be reduced to 75 percent of that number by the end of the 50-year simulation period.

3.2.4.2.1 Spawning Area

Spawning areas for the assessment reaches below the proposed dam site were calculated by determining the estimated average flow during the spawning period for each species, then running the model using WUA as described in Section 3.2.4.1. For the Upper Watershed to Proposed Dam Site reach, the available spawning habitat was estimated based on the HEP results. The spawning area calculations, including the average flows used in the analysis, are provided in Table F-11.

Table F-11

Average River Flows and Estimated Spawning Area with a Flood Storage Only Dam

Reach	Average River Flow During Spawning Period (cfs)			Spawning Area (m^2)		
	Spring Chinook	Winter Steelhead	Coho	Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	40	416	796	4,269	107,029	122,378
Proposed Dam Site to Elk Creek	40	416	796	6,014	29,701	16,836
Elk Creek to South Fork Chehalis	40	416	796	42	5,092	4,700
South Fork Chehalis to Newaukum River	40	416	796	500	0	0
Newaukum River to Skookumchuck River	293	2,227	3,899	0	0	0
Skookumchuck River to Black River	293	2,227	3,899	161,705	0	0
Black River to Porter	440	3,385	5,673	212,793	0	0

3.2.4.2.2 Rearing Area

Rearing areas for the reaches below the proposed dam site were calculated by determining the estimated average flow during the rearing period for each species, then running the model using WUA as described for existing conditions (Section 3.2.4.1). Separate rearing area estimates were prepared for spring rearing (March 1 through June 30), summer rearing (July 1 through September 30) and overwinter rearing (October 1 through February 28). Flow estimates were calculated as the mean flow during each rearing period.

The amount of overwinter rearing area was calculated using the same methods described for the existing conditions analysis (Section 3.2.4.1). The only change from existing conditions for the flood storage only scenario was in the Upper Watershed to Proposed Dam Site reach where rearing areas within the footprint of the entire reservoir inundation area were assumed to be unsuitable. This habitat estimate was made based on the expectation that habitat in the reservoir footprint will be highly altered, even though the reservoir will not be present except during high-flow events and for short periods after them. The percentage of reach length providing suitable overwinter habitat in the flood storage only scenario is presented in Table F-12.

Table F-12
Percentage of Reach Length Providing Overwinter Habitat for Salmonids with a Flood Storage Only Dam

Reach	Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	30%	38%	12%
Proposed Dam Site to Elk Creek	5%	5%	5%
Elk Creek to South Fork Chehalis	3%	3%	3%
South Fork Chehalis to Newaukum River	4%	4%	4%
Newaukum River to Skookumchuck River	0%	0%	0%
Skookumchuck River to Black River	1%	1%	1%
Black River to Porter	1%	1%	1%

The rearing area calculations, including the average flows used in the analysis, are provided for spring rearing in Table F-13, summer rearing in Table F-14, and overwinter rearing in Table F-15.

Table F-13
Average River Flows and Estimated Spring Rearing Area with a Flood Storage Only Dam

Reach	Average River Flow During Spring Rearing Period (cfs)	Spring Rearing Area (m^2)		
		Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	343	63,715	168,256	49,327
Proposed Dam Site to Elk Creek	343	39,497	42,468	42,468
Elk Creek to South Fork Chehalis	343	111,851	108,788	108,788
South Fork Chehalis to Newaukum River	343	125,174	108,305	108,305
Newaukum River to Skookumchuck River	1,864	0	0	0
Skookumchuck River to Black River	1,864	353,383	330,289	330,289
Black River to Porter	2,816	73,852	63,646	63,646

Table F-14
Average River Flows and Estimated Summer Rearing Area with a Flood Storage Only Dam

Reach	Average River Flow During Summer Rearing Period (cfs)	Summer Rearing Area (m^2) Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	41	63,715	168,256	49,327
Proposed Dam Site to Elk Creek	41	39,497	42,468	42,468
Elk Creek to South Fork Chehalis	41	38,393	27,438	27,438
South Fork Chehalis to Newaukum River	41	50,000	30,000	30,000
Newaukum River to Skookumchuck River	290	0	0	0
Skookumchuck River to Black River	290	371,014	262,336	262,336
Black River to Porter	459	136,154	112,904	112,904

Table F-15
Average River Flows and Estimated Overwinter Rearing Area with a Flood Storage Only Dam

Reach	Average River Flow During Overwinter Rearing Period (cfs)	Overwinter Rearing Area (m^2) Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	622	31,857	37,016	10,852
Proposed Dam Site to Elk Creek	622	1,333	1,429	1,429
Elk Creek to South Fork Chehalis	622	2,796	2,834	2,834
South Fork Chehalis to Newaukum River	622	5,024	4,771	4,771
Newaukum River to Skookumchuck River	3,063	0	0	0
Skookumchuck River to Black River	3,063	2,001	1,996	1,996
Black River to Porter	4,671	756	603	603

3.2.4.3 Habitat Capacity Inputs for a Multi-Purpose Dam With Operations to Maximize Available Fish Habitat Scenario

The construction and operation of a multi-purpose dam would alter the availability of suitable habitat for each life stage through changes in flow rates during high-flow events, as well as through changes in bedload transport and other natural processes. There are two primary differences between habitat availability with a multi-purpose dam compared to a flood storage only dam. First, the operation of a multi-purpose dam would continuously maintain a reservoir upstream of the dam. The water levels in the reservoir would be adjusted for flood storage and hydropower purposes, but a large reservoir would be present throughout the year. Second, the operation of a multi-purpose dam would allow for the release of water in order to augment low flows downstream of the dam. This would increase the amount of habitat available in reaches downstream of the dam.

It was assumed that a multi-purpose dam would be operated to manage flow releases (up to an outtake maximum release flow of 2,000 cubic feet per second [cfs]) for the benefit of fish. This ability to vary release flows coupled with the water storage in the reservoir would allow for the release of available water from the reservoir to be optimized to maximize the available fish habitat throughout the year. The optimized scenario in this study assumed flows were regulated to maximize fish habitat rather than hydropower generation. The habitat capacity inputs in the optimized scenario were identified by completing the following steps. First, the life history information presented in Section 3.2.3.1 was applied to identify the species and life stages present during each month. Second, a priority species and life stage was identified for each month. To address the overlaps in the timing of different species and life stages during the same month, priority was assigned to spawning over rearing. Once the priority species and life stages were identified, then the assessment reaches in which to focus efforts to maximize flows were identified. The priority reaches, all downstream of the dam where flows could be manipulated, were determined based on the life stage distribution data presented in Sections 3.2.3.2 and 3.2.3.3. Table F-16 presents the priority species and life stage identified for each month, as well as the target assessment reach for maximizing habitat.

Table F-16
Priority Species and Life Stages Identified for Each Month in the Optimized Multi-Purpose Dam Analysis

Month	Species and Life Stage	Priority Reaches In which to Maximize Habitat Area
January	Coho salmon adult spawning	Proposed Dam Site to Elk Creek
February	Coho salmon adult spawning	Proposed Dam Site to Elk Creek
March	Winter steelhead adult spawning	Proposed Dam Site to Elk Creek and Elk Creek to South Fork Chehalis
April	Winter steelhead adult spawning	Proposed Dam Site to Elk Creek and Elk Creek to South Fork Chehalis
May	Winter steelhead adult spawning	Proposed Dam Site to Elk Creek and Elk Creek to South Fork Chehalis
June	Winter steelhead adult spawning	Proposed Dam Site to Elk Creek and Elk Creek to South Fork Chehalis
July	All species juvenile rearing	Proposed Dam Site to Elk Creek and Elk Creek to South Fork Chehalis
August	Spring Chinook salmon adult spawning	Proposed Dam Site to Elk Creek and Elk Creek to South Fork Chehalis
September	Spring Chinook salmon adult spawning	Proposed Dam Site to Elk Creek and Elk Creek to South Fork Chehalis
October	Spring Chinook salmon adult spawning	Proposed Dam Site to Elk Creek and Elk Creek to South Fork Chehalis
November	Coho salmon adult spawning	Proposed Dam Site to Elk Creek
January	Coho salmon adult spawning	Proposed Dam Site to Elk Creek

Next, the habitat availability data from the PHABSIM analysis (see main report Appendix D) were used to identify the percentage of the maximum possible amount of habitat provided at various flow rates. The flows providing 80 to100 percent of maximum possible amount of habitat were identified for each target reach. This information was combined to identify a target flow to maximize habitat that would provide the most habitat for the priority species and life stage in the priority reaches. The following recommended target flows were identified: 300 cfs for coho salmon spawning, 250 cfs for winter steelhead spawning, 240 cfs for spring Chinook salmon spawning, and 200 cfs for juvenile rearing. Recognizing that the quantity of water available for release varies by year depending on how wet or dry the year is, secondary fish flow recommendation was provided. The secondary targets require less water and provide 80 percent or more of the maximum WUA. The secondary targets identified were: 250 cfs for coho salmon spawning, 200 cfs for winter steelhead spawning, 160 cfs for spring Chinook salmon spawning, and 150 cfs for juvenile rearing.

With this information on target flows, a hydrologic analysis was conducted to identify a flow release schedule that most closely provides the target flows given the amount of water available in the reservoir over the course of the year. The hydrologic analysis results are presented in Appendix A of the main report. The flow release schedule presented in Table F-17 was identified to maximize fish habitat given available water. The flow releases provide flows as close to the target flows as possible.

Table F-17
Optimized Flow Release Schedule to Maximize Fish Habitat

Month	Species and Life Stage	Flow Release (cfs)
January	Coho salmon adult spawning	250
February	Coho salmon adult spawning	250
March	Winter steelhead adult spawning	200
April	Winter steelhead adult spawning	200
May	Winter steelhead adult spawning	200
June	Winter steelhead adult spawning	200
July	All species juvenile rearing	150
August	Spring Chinook salmon adult spawning	160
September	Spring Chinook salmon adult spawning	160
October	Spring Chinook salmon adult spawning	160
November	Coho salmon adult spawning	250
January	Coho salmon adult spawning	250

The flow releases were applied to estimate habitat area using PHABSIM results for each reach downstream of the dam. To account for the flow rate changes, estimated future flow rates with a flood control dam were applied to the PHABSIM results to calculate habitat area. In a process identical to the approach described for the flood storage only analysis, available habitat with a multi-purpose dam was estimated by running a revised PHABSIM analysis assuming additional deposition of finer grained (i.e., sand) bedload, which would be expected in the reaches upstream of the confluence with the South Fork Chehalis River. As described in the existing conditions section (3.2.4.1), the quantity of habitat was calculated for each species and life stage using the PHABSIM (with adjusted substrate conditions) and HEP results.

Also identical to the flood storage analysis, model inputs for habitat area were adjusted to account for the interruption of sediment bedload and large woody debris transport from the upper watershed to reaches below the dam, as well as the reduction in higher channel maintenance flows. These interruptions to natural river processes were accounted for in the model through the use of a habitat decay factor that was applied to all reaches downstream of the proposed dam site. The habitat decay factor was established to reduce the amount of habitat by 0.5 percent per year, so that by the end of the 50-year simulation period, the available habitat below the dam is approximately 75 percent of the amount estimated in the existing conditions analysis. In this way, the habitat area numbers presented in the following tables represent the year-1 conditions and would be reduced to 75 percent of that number by the end of the 50-year simulation period.

3.2.4.3.1 Spawning Area

Spawning areas for the assessment reaches below the proposed dam site were calculated by determining the estimated average flow during the spawning period of each species, then conducting the modeling using WUA as described for existing conditions (Section 3.2.4.1.1). For the Upper Watershed to Proposed Dam Site reach, the available spawning habitat was estimated based on the HEP results. The spawning area calculations, including the average flows used in the analysis, are provided in Table F-18.

Table F-18
Average River Flows and Estimated Spawning Area in the Multi-Purpose Dam Scenario

Reach	Average River Flow During Spawning Period (cfs)			Spawning Area (m^2)		
	Spring Chinook	Winter Steelhead	Coho	Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	40	416	760	0	100,527	111,326
Proposed Dam Site to Elk Creek	169	450	501	25,766	28,789	25,445
Elk Creek to South Fork Chehalis	169	450	501	1,433	5,310	5,947
South Fork Chehalis to Newaukum River	169	450	501	38,271	0	0
Newaukum River to Skookumchuck River	422	2,261	3,526	0	0	0
Skookumchuck River to Black River	422	2,261	3,526	325,442	0	0
Black River to Porter	569	3,419	5,259	274,766	0	0

3.2.4.3.2 Rearing Area

Rearing area with a multi-purpose dam was calculated using the modifications described above and the calculation steps explained in Section 3.2.4.1.2 for existing conditions. Separate rearing area estimates were prepared for spring rearing (March 1 through June 30), summer rearing (July 1 through September 30), and overwinter rearing (October 1 through February 28). Flow estimates were calculated as the mean flow during each rearing period.

The amount of overwinter rearing area was calculated using the same methods described for the existing conditions analysis (Section 3.2.4.1.2). The only change from existing conditions for the multi-purpose dam scenario was in the Upper Watershed to Proposed Dam Site reach where rearing areas within the footprint of the entire reservoir inundation area were assumed to be unsuitable. This habitat estimate was made due to the expectation that habitat in the reservoir footprint will be highly altered, even though the reservoir will not be present except during high flow events and soon after them. The percentage of reach length providing suitable overwinter habitat in the multi-purpose dam scenario is presented in Table F-19.

Table F-19
Percentage of Reach Length Providing Overwinter Habitat for Salmonids with a Multi-Purpose Dam

Reach	Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	28%	35%	11%
Proposed Dam Site to Elk Creek	5%	5%	5%
Elk Creek to South Fork Chehalis	3%	3%	3%
South Fork Chehalis to Newaukum River	4%	4%	4%
Newaukum River to Skookumchuck River	0%	0%	0%
Skookumchuck River to Black River	1%	1%	1%
Black River to Porter	1%	1%	1%

The rearing area calculations for the multi-purpose dam scenario, including the average flows used in the analysis, are provided for spring rearing, summer rearing, and overwinter rearing in Tables F-20, F-21, and F-22, respectively.

Table F-20
Average River Flows and Estimated Spring Rearing Area with a Multi-Purpose Dam

Reach	Average River Flow During Spring Rearing Period (cfs)	Spring Rearing Area (m^2)		
		Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	343	59,293	154,619	44,487
Proposed Dam Site to Elk Creek	392	35,963	39,762	39,762
Elk Creek to South Fork Chehalis	392	109,405	109,144	109,144
South Fork Chehalis to Newaukum River	392	129,930	113,584	113,584
Newaukum River to Skookumchuck River	1,913	0	0	0
Skookumchuck River to Black River	1,913	338,128	319,899	319,899
Black River to Porter	2,865	73,852	63,646	63,646

Table F-21
Average River Flows and Estimated Summer Rearing Area with a Multi-Purpose Dam

Reach	Average River Flow During Summer Rearing Period (cfs)	Summer Rearing Area (m^2)		
		Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	41	59,293	154,619	44,487
Proposed Dam Site to Elk Creek	171	43,829	44,197	44,197
Elk Creek to South Fork Chehalis	171	97,307	81,836	81,836
South Fork Chehalis to Newaukum River	171	94,535	72,587	72,587
Newaukum River to Skookumchuck River	420	0	0	0
Skookumchuck River to Black River	420	501,413	348,672	348,672
Black River to Porter	589	135,049	118,789	118,789

Table F-22

Average River Flows and Estimated Overwinter Rearing Area with a Multi-Purpose Dam

Reach	Average River Flow During Overwinter Rearing Period (cfs)	Overwinter Rearing Area (m^2)		
		Spring Chinook	Winter Steelhead	Coho
Upper Watershed to Proposed Dam Site	601	16,602	34,016	9,787
Proposed Dam Site to Elk Creek	486	1,537	1,697	1,697
Elk Creek to South Fork Chehalis	486	3,068	3,116	3,116
South Fork Chehalis to Newaukum River	486	5,285	4,782	4,782
Newaukum River to Skookumchuck River	2,948	0	0	0
Skookumchuck River to Black River	2,948	2,001	1,996	1,996
Black River to Porter	4,461	751	605	605

3.2.5 Habitat Productivity Model Inputs

The quality of habitat affects salmonid survival from one life stage to the next either through direct mortality or through an indirect reduction in the fishes' fitness and growth. In an unaltered environment, the survival of salmonids is influenced by a wide range of factors. The influence of some habitat parameters on the survival of salmonids is better known than others. Also, the scientific community's understanding of the effects of habitat parameters on survival is more complete for some parameters than others. In creating a model to estimate salmonid population growth, this study did not attempt to include all possible parameters that may affect the species. Such an undertaking would be exceedingly complex and would require an abundance of data far beyond what is available in the Chehalis River Basin. Such an approach would also risk understating the uncertainty associated with any effort to predict how a fish population size will respond to the complete array of ecological conditions. Instead, the approach taken in this study was to use available data from the scientific literature that describe the biological requirements of salmonids, and to develop a predictive model that relies upon as few habitat parameters as necessary to effectively calibrate the model to previous observations of salmonid returns to the river.

This analytical approach started by identifying data sets that were available for the study area. Next, through an iterative process, parameters used in the models for each species were added or subtracted based on their yielding adult spawner abundance that best calibrated model outputs to the spawner estimates prepared by WDFW. Table F-23 lists the habitat productivity parameters included for each species and life stage.

Table F-23

Habitat Productivity Parameters Used in Salmonid Models to Estimate Life Stage Survival

Life Stage	Spring Chinook	Winter Steelhead	Coho
Adult spawning	• Maximum temperature • Upstream passage by dam	• Maximum temperature • Upstream passage by dam	• Maximum temperature • Upstream passage by dam
Egg incubation	• Fine sediments • Minimum or maximum temperature • Peak flow	• Fine sediments • Peak flow	• Fine sediments • Minimum or maximum temperature
Juvenile spring rearing	• Median temperature • Baseline survival rate		
Juvenile summer rearing	• Minimum flow • Median temperature • Baseline survival	• Minimum flow	• Minimum flow
Juvenile overwinter rearing	• Baseline survival	• Baseline survival	• Baseline survival
Smolt-to-Adult ocean	• Marine survival • Downstream passage by dam	• Marine survival • Downstream passage by dam	• Marine survival • Downstream passage by dam

The following sections discuss the parameters used in the models for each species life stage, each parameter's functional relationship with salmonid survival, and the data used in the analysis. Model inputs of these parameters to characterize conditions during the calibration period were based on existing data from a variety of sources. Model inputs for future conditions were characterized as distributions (i.e., linear, normal, or log-normal) for which the model randomly (stochastically) determined inputs for a given year.

3.2.5.1 Adult Pre-Spawn Survival

Adult survival from river entry through spawning was estimated for all three species based on maximum water temperatures. For those scenarios with a dam in place, upstream passage past the dam and reservoir also affected the survival of adults migrating to the upper watershed reach.

3.2.5.1.1 Maximum Temperature

Adults of all three species are in the river for some or all of the summer months when temperatures are warm and may exceed thresholds beyond which survival is affected. Cramer (2001) developed a mathematical function between adult pre-spawn mortality and water temperatures based on observations of hatchery and wild spring Chinook in the Rogue River. The functional relationship developed by Cramer (2001) has been used in other fish population studies by Scheuerell et al. 2006 (Snohomish River) and Honea et al. 2009 (Columbia River) and is used in this analysis.

The mathematical function characterizing the proportion of adults surviving (p_i) is as follows and shown in Figure F-3:

$$p_i = \begin{cases} 1 & \text{if } T_{pre} < 16 \\ 1 - 0.15(T_{pre} - 16) & \text{if } 16 \leq T_{pre} \leq 22.6 \\ 0.01 & \text{if } T_{pre} \geq 22.6 \end{cases}$$

where T_{pre} (in degrees Celsius) is the maximum water temperature

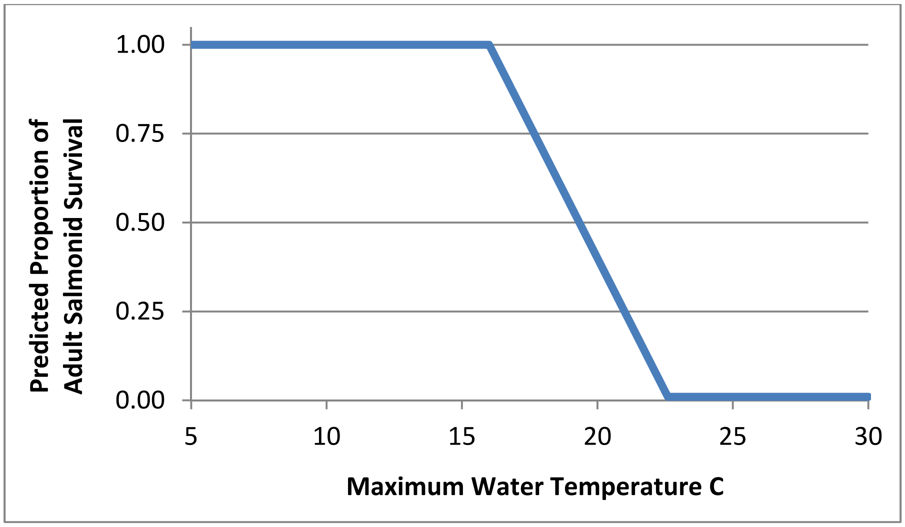


Figure F-3
Functional Relationship between Maximum Water Temperature and Adult Salmonid Survival

Cramer (2001) used the maximum June temperature. Scheuerell et al. (2006) used the maximum temperature observed during a portion of spawning period (July 15 through August 15). Honea et al. (2009) used the mean of the maximum daily temperature in August and September.

Continuous or daily long-term temperature data were not available for the Chehalis River. As the best available data set, the monthly water temperature data collected by the Washington State Department of Ecology's (Ecology's) River and Stream Water Quality Monitoring Program (http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html) was used. Ecology has two stations on the mainstem Chehalis River that have been sampled over a long period. A station at Porter (code 23A070, RM 33.3) has been sampled monthly since 1959 (except in 1974), and a station at Dryad (code 23A160, RM 97.9) has been sampled monthly in water years 1959 through 1966 and from 1978 to the present. In this fish study, temperature data from water years 1978 through 2010 were used.

The maximum water temperatures observed during each species' spawning period were used in the analysis. Among spring Chinook salmon, the analysis was based on maximum temperatures between August and October. The winter steelhead analysis was based on maximum water temperatures between March and May. The coho salmon analysis was based on maximum water temperatures between November and January. Temperatures from Ecology's Dryad monitoring station were used in the four reaches upstream from the Newaukum River. Temperatures from Ecology's monitoring station at Porter were applied to the three reaches downstream from the Newaukum River.

In the model calibration period from 1978 through 2010, data from Ecology were used. To estimate annual maximum water temperatures in future years, the model was set to randomly (stochastically) assign a water temperature using a water temperature regime with a normal distribution and a defined mean and standard deviation. This information was calculated using Ecology's data at the Porter and Dryad stations, as well as the predictions from the water quality analysis conducted in this study (see Appendix C of the main report). Using Ecology's data, the first step was to calculate the average and standard deviation of the annual maximum observations over the last 20 years for those months when the adult fish of each species are in the river. For the existing conditions and flood storage only analyses, this information was used as is. For the multi-purpose dam analysis, the estimated changes to water quality were added or subtracted to the average calculated using Ecology's data. This calculation was conducted separately for each study reach, each species, and both dam scenarios. The predicted average temperatures during the spawning period are provided in Tables F-24, F-25, and F-26.

Table F-24
Maximum Temperatures Predicted During Spring Chinook Salmon Spawning Period

Reach	Maximum Temperature (°C, ± standard deviation) In Existing and Flood Storage Only Analyses	Maximum Temperature (°C, ± standard deviation) In Multi-Purpose Dam Analysis	Temperature Difference (°C) between Multi-Purpose Dam and Existing Conditions
Upper Watershed to Proposed Dam Site	17.9 ± 2.4	19.6[a] ± 2.4	+1.7
Proposed Dam Site to Elk Creek	17.9 ± 2.4	17.7 ± 2.4	-0.2
Elk Creek to South Fork Chehalis	17.9 ± 2.4	18.0 ± 2.4	+0.1
South Fork Chehalis to Newaukum River	17.9 ± 2.4	18.0 ± 2.4	+0.1
Newaukum River to Skookumchuck River	18.9 ± 1.9	19.0 ± 1.9	+0.1
Skookumchuck River to Black River	18.9 ± 1.9	19.0 ± 1.9	+0.1
Black River to Porter	18.9 ± 1.9	19.0 ± 1.9	+0.1

Note: a) Maximum temperature in the Upper Watershed reach in the multi-purpose analysis was based on the estimated surface water temperature modeled for the reservoir (calculated in main report Appendix C).

Table F-25
Maximum Temperatures Predicted During Winter Steelhead Spawning Period

Reach	Maximum Temperature (°C, ± standard deviation) In Existing and Flood Storage Only Analyses	Maximum Temperature (°C, ± standard deviation) In Multi-Purpose Dam Analysis	Temperature Difference (°C) Between Multi-Purpose Dam and Existing Conditions
Upper Watershed to Proposed Dam Site	12.7 ± 2.0	12.5[a] ± 2.0	+0.2
Proposed Dam Site to Elk Creek	12.7 ± 2.0	10.2 ± 2.0	-2.5
Elk Creek to South Fork Chehalis	12.7 ± 2.0	10.8 ± 2.0	-1.9
South Fork Chehalis to Newaukum River	12.7 ± 2.0	12.1 ± 2.0	-0.6
Newaukum River to Skookumchuck River	14.7 ± 2.2	14.5 ± 2.2	-0.2
Skookumchuck River to Black River	14.7 ± 2.2	14.6 ± 2.2	-0.1
Black River to Porter	14.7 ± 2.2	14.7 ± 2.2	+0.0

Note: a) Maximum temperature in the Upper Watershed reach in the multi-purpose analysis was based on the estimated surface water temperature modeled for the reservoir (calculated in main report Appendix C).

Table F-26
Maximum Temperatures Predicted During Coho Salmon Spawning Period

Reach	Maximum Temperature (°C, ± standard deviation) In Existing and Flood Storage Only Analyses	Maximum Temperature (°C, ± standard deviation) In Multi-Purpose Dam Analysis	Temperature Difference (°C) Between Multi-Purpose Dam and Existing Conditions
Upper Watershed to Proposed Dam Site	7.8 ± 1.5	8.3 ± 1.5	+0.5
Proposed Dam Site to Elk Creek	7.8 ± 1.5	8.3 ± 1.5	+0.5
Elk Creek to South Fork Chehalis	7.8 ± 1.5	8.2 ± 1.5	+0.4
South Fork Chehalis to Newaukum River	7.8 ± 1.5	7.9 ± 1.5	+0.1
Newaukum River to Skookumchuck River	8.0 ± 1.4	8.1 ± 1.4	+0.1
Skookumchuck River to Black River	8.0 ± 1.4	8.0 ± 1.4	+0.0
Black River to Porter	8.0 ± 1.4	8.0 ± 1.4	+0.0

Note: a) Maximum temperature in the Upper Watershed reach in the multi-purpose analysis was based on the estimated surface water temperature modeled for the reservoir (calculated in main report Appendix C).

3.2.5.1.2 Upstream Fish Passage Survival

The survival rates presented in Section 3.2.3.4 for adult salmonids migrating past the dam and reservoir upstream were used in this analysis. These rates were only applied to those adult fish migrating into the Upper Watershed to Proposed Dam Site reach to spawn.

3.2.5.2 Egg Incubation Survival

The habitat parameters used to estimate egg incubation survival varied between the species analyzed. For spring Chinook salmon, egg incubation survival was related to the amount of fine sediments, the peak flows during the incubation period, and the minimum or maximum water temperatures during the incubation period. For winter steelhead, egg incubation survival was related to the amount of fine sediments and the peak flows during the incubation period. For coho salmon, egg incubation survival was related to the amount of fine sediments and the minimum or maximum water temperatures during the incubation period.

3.2.5.2.1 Fine Sediments

Higher percentages of fine sediments in spawning substrates have been documented to substantially reduce egg-to-fry survival (Tappel and Bjornn 1983; Chapman and McLeod 1987). Different studies have used different size categories for "fine" sediments and their effect on egg survival. In this study, a functional relationship was developed based on fines smaller than 0.85 millimeter (mm). This is a commonly applied substrate size in assessing egg incubation survival and is ecologically valid. Based on information in Bjornn and Reiser (1991) that indicated steelhead are more sensitive to fine sediments than Chinook and coho salmon, a separate function relationship was developed for steelhead. The functional relationships were developed using a composite of data from Tappel and Bjornn (1983), Cederholm et al. (1981), McHenry et al. (1994), and Honea et al. (2009).

For spring Chinook and coho salmon, the relationship between the proportion of eggs surviving (p_i) and the percentage of fine sediments (f; <0.85 mm diameter) is as follows and shown in Figure F-4:

$$p_i = \begin{array}{ll} 1 & \text{if } f < 10\% \\ 0.8 & \text{if } f = 12\% \\ 0.4 & \text{if } f = 20.4\% \\ 0.07 & \text{if } f = 28\% \\ 0.04 & \text{if } f \geq 50\% \end{array}$$

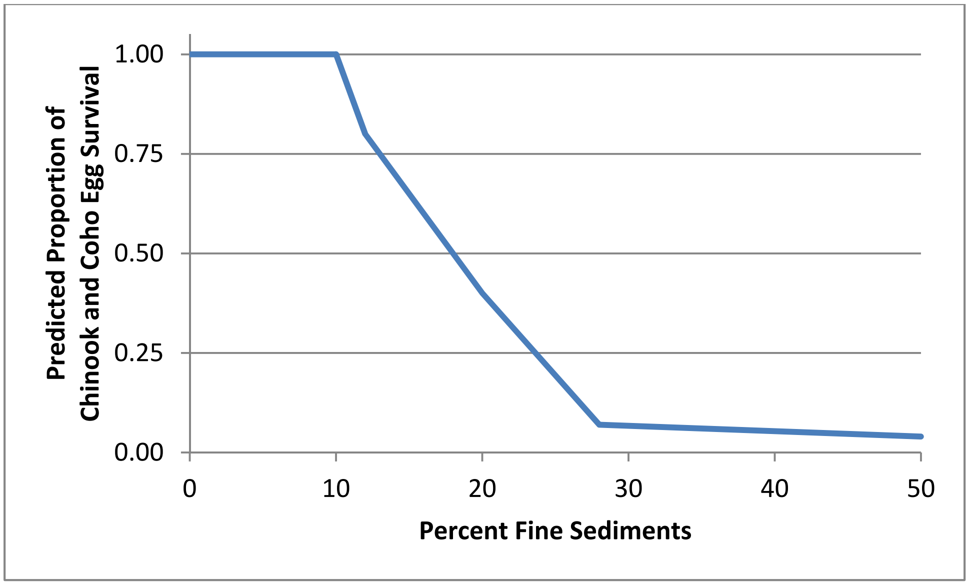


Figure F-4

Functional Relationship between Percent Fine Sediments and Spring Chinook and Coho Salmon Egg Survival

For winter steelhead, the relationship between the proportion of eggs surviving (p_i) and the percentage of fine sediments (f; <0.85 mm diameter) is as follows and shown in Figure F-5:

$$
p_i = \begin{array}{ll}
1 & \text{if } f < 8\% \\
0.6 & \text{if } f = 13\% \\
0.2 & \text{if } f = 20.4\% \\
0.07 & \text{if } f = 25\% \\
0.04 & \text{if } f \geq 50\%
\end{array}
$$

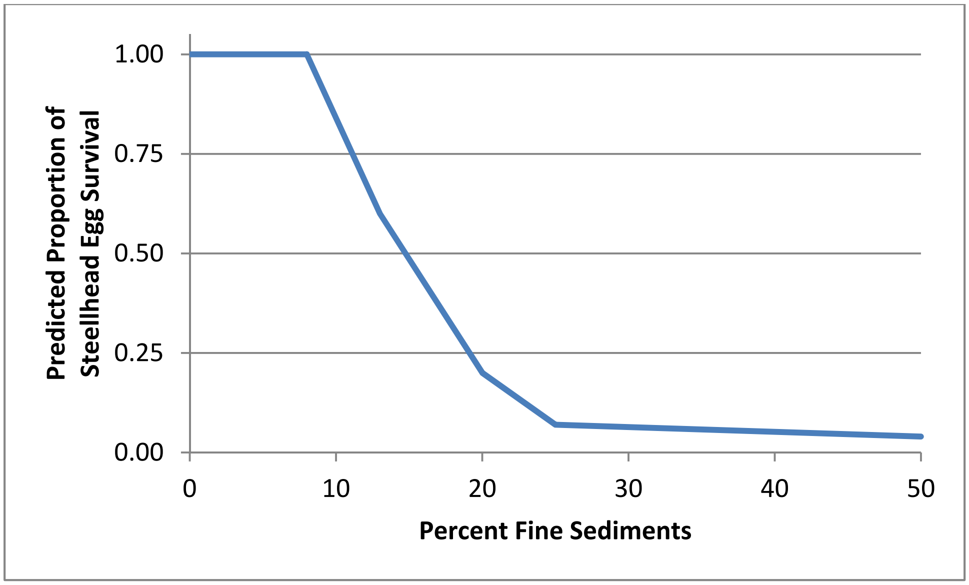


Figure F-5
Functional Relationship between Percent Fine Sediments and Winter Steelhead Egg Survival

Fine sediment data were collected as part of the sediment transport data collection and analysis (see Appendix B of main report). The percentage of fine sediments (smaller than 0.85 mm) was determined for each study reach based on two to five samples from each reach.

These data were used in the existing conditions analysis. In the flood storage only and multi-purpose dam scenarios, the percentage of fine sediments was increased based on the sediment transport analysis, which found that some additional fine sediments are expected to occur downstream of the dam, especially in the reaches closest to the dam. Based on this finding of the sediment transport analysis, estimates of the future percent fines were developed for the model (Table F-27). Due to the challenges in quantifying such changes, these are to be considered general estimates.

Table F-27

Percent Fine Sediment (<0.85 mm) in Substrate of Each Reach

Reach	Percent Fines		
	Existing Conditions	Flood Storage Only Dam	Multi-Purpose Dam
Upper Watershed to Proposed Dam Site	10	10[a]	10[a]
Proposed Dam Site to Elk Creek	10	24	24
Elk Creek to South Fork Chehalis	18	24	24
South Fork Chehalis to Newaukum River	15	23	23
Newaukum River to Skookumchuck River	24	30	30
Skookumchuck River to Black River	11	15	15
Black River to Porter	10	12	12

Note: a) Upper watershed reach fine sediment percentages are not expected to change above the reservoir. Higher percentages of fine sediments would be expected in the reservoir, but no spawning or egg incubation is expected in the reservoir.

3.2.5.2.2 Peak Flows

High water flows can scour or bury salmonid eggs, decreasing survivorship (McHenry et al. 1994). Work by WDFW has long documented a strong relationship between the peak flows during egg incubation and egg survival (see Seiler et al. 2003). In this analysis, a functional relationship developed by Scheuerell et al. (2006) was used. Egg-to-fry survival was calculated as a linear function of the proportion of the maximum daily flow divided by the 100-year maximum flow. Scheuerell et al. (2006) identified an egg-to-fry survival relationship that was a derivative of an egg-to smolt relationship identified by Seiler et al. (2003). Peak flows during incubation were used to estimate egg survival of spring Chinook and winter steelhead. For spring Chinook, the egg incubation period analyzed was September through February. For winter steelhead, the egg incubation period analyzed was March through July. The proportion of eggs surviving ($p_{2,2}$) based on flow conditions is calculated using the following formula as shown in Figure F-6:

$$p_i = \begin{cases} 0.58 - 0.844Q^* & \text{if } Q^* < 0.675 \\ 0.01 & \text{if } Q^* \geq 0.675 \end{cases}$$

where Q^* is the maximum daily flow divided by to 100-year maximum flow

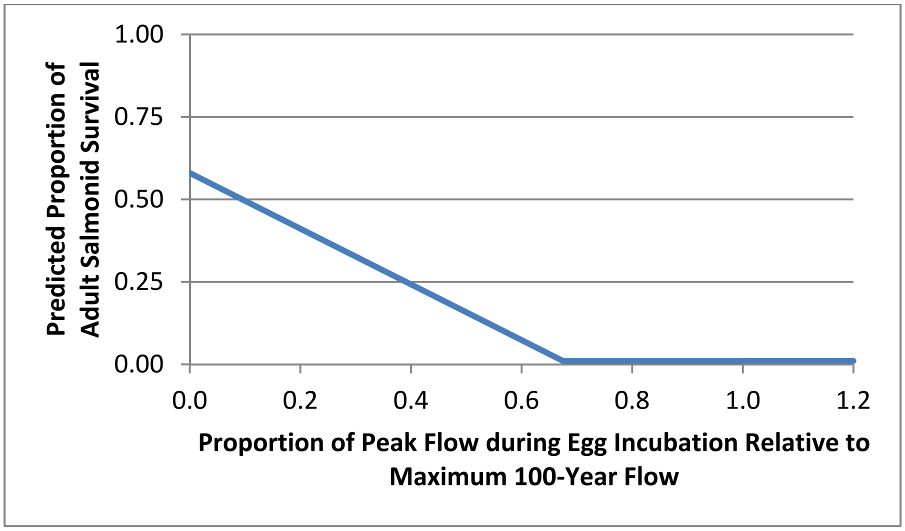


Figure F-6
Functional Relationship between Peak Flow During Egg Incubation and Egg Survival

In this study, the same functional relationship was used for spring Chinook salmon, winter steelhead, and coho salmon. Flow data from the hydrology analysis conducted in this study were used (see main report Appendix A). This calculation was conducted separately for each study reach, each species, and both dam scenarios. The future peak flow predictions assuming a log-normal distribution are presented in Tables F-28, F-29, and F-30.

Table F-28
Peak Flows During Spring Chinook Salmon Egg Incubation Period Relative to 100-year Maximum Flow

Analysis Scenario	Proportion of Peak Flows During Egg Incubation Period Relative to 100-Year Maximum Flow (Mean ± Coefficient of Variation)		
	Existing Conditions	Flood Storage Only Dam	Multi-Purpose Dam
Upper Watershed to Proposed Dam Site	0.270 ± 0.778	0.151 ± 0.541	0.127 ± 0.664
Proposed Dam Site to Elk Creek	0.270 ± 0.778	0.151 ± 0.541	0.127 ± 0.664
Elk Creek to South Fork Chehalis	0.270 ± 0.778	0.151 ± 0.541	0.127 ± 0.664
South Fork Chehalis to Newaukum River	0.270 ± 0.778	0.151 ± 0.541	0.127 ± 0.664
Newaukum River to Skookumchuck River	0.420 ± 0.489	0.375 ± 0.441	0.367 ± 0.450
Skookumchuck River to Black River	0.420 ± 0.489	0.375 ± 0.441	0.367 ± 0.450
Black River to Porter	0.420 ± 0.489	0.375 ± 0.441	0.367 ± 0.450

Table F-29
Peak Flows During Winter Steelhead Salmon Egg Incubation Period Relative to 100-Year Maximum Flow

Analysis Scenario	Proportion of Peak Flows During Egg Incubation Period Relative to 100-Year Maximum Flow (Mean ± Coefficient of Variation)		
	Existing Conditions	**Flood Storage Only Dam**	**Multi-Purpose Dam**
Upper Watershed to Proposed Dam Site	0.060 ± 1.156	0.076 ± 0.464	0.053 ± 0.510
Proposed Dam Site to Elk Creek	0.060 ± 1.156	0.076 ± 0.464	0.053 ± 0.510
Elk Creek to South Fork Chehalis	0.060 ± 1.156	0.076 ± 0.464	0.053 ± 0.510
South Fork Chehalis to Newaukum River	0.060 ± 1.156	0.076 ± 0.464	0.053 ± 0.510
Newaukum River to Skookumchuck River	0.199 ± 0.513	0.194 ± 0.477	0.187 ± 0.471
Skookumchuck River to Black River	0.199 ± 0.513	0.194 ± 0.477	0.187 ± 0.471
Black River to Porter	0.199 ± 0.513	0.194 ± 0.477	0.187 ± 0.471

Table F-30
Peak Flows During Coho Salmon Egg Incubation Period Relative to 100-Year Maximum Flow

Analysis Scenario	Proportion of Peak Flows During Egg Incubation Period Relative to 100-Year Maximum Flow (Mean ± Coefficient of Variation)		
	Existing Conditions	Flood Storage Only Dam	Multi-Purpose Dam
Upper Watershed to Proposed Dam Site	0.272 ± 0.775	0.152 ± 0.540	0.127 ± 0.664
Proposed Dam Site to Elk Creek	0.272 ± 0.775	0.152 ± 0.540	0.127 ± 0.664
Elk Creek to South Fork Chehalis	0.272 ± 0.775	0.152 ± 0.540	0.127 ± 0.664
South Fork Chehalis to Newaukum River	0.272 ± 0.775	0.152 ± 0.540	0.127 ± 0.664
Newaukum River to Skookumchuck River	0.421 ± 0.486	0.376 ± 0.437	0.368 ± 0.446
Skookumchuck River to Black River	0.421 ± 0.486	0.376 ± 0.437	0.368 ± 0.446
Black River to Porter	0.421 ± 0.486	0.376 ± 0.437	0.368 ± 0.446

3.2.5.2.3 Water Temperature

Incubating eggs are sensitive to high or low water temperatures. Egg-to-fry survivorship is influenced by water temperatures in a non-linear function as decreased survival occurs above and below an optimum range (Fowler 1972; Murray and McPhail 1988). Separate functional relationships were used for spring Chinook salmon and coho salmon.

A functional relationship for spring Chinook salmon was developed by Scheuerell et al. (2006) and also applied by Honea et al. (2009). The mathematical function characterizing the proportion of spring Chinook salmon eggs (p_i) surviving related to maximum or minimum water temperature of adults surviving (p_i) is as follows and shown in Figure F-7:

$$
\begin{array}{lll}
p_i = & 0.01 & \text{if } T_{min} = 0.0 \\
 & 0.01 & \text{if } T_{min} = 1.3 \\
 & 0.94 & \text{if } T_{min} = 4.7 \\
 & 0.94 & \text{if } T_{max} = 14.3 \\
 & 0.01 & \text{if } T_{max} = 18.0 \\
 & 0.01 & \text{if } T_{max} = 30.0
\end{array}
$$

where T_{min} (in degrees Celsius) is the minimum water temperature and T_{max} (in degrees Celsius) is the maximum water temperature

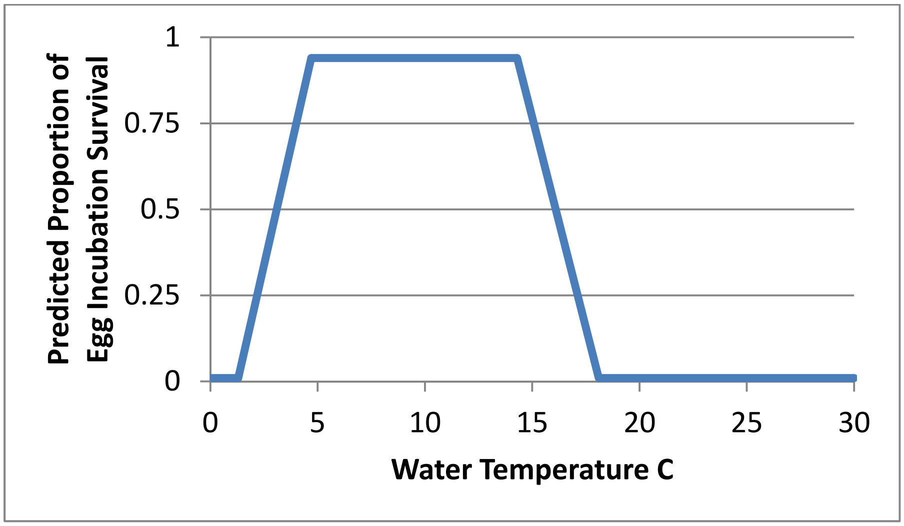


Figure F-7

Functional Relationship between Water Temperature and Spring Chinook Salmon Egg Incubation Survival

A functional relationship for coho salmon was developed based on the Habitat Suitability Index developed by McMahon (1983). The mathematical function characterizing the proportion of coho salmon eggs (p_i) surviving related to maximum or minimum water temperature of adults surviving (p_i) is as follows and shown in Figure F-8:

$$
\begin{array}{lll}
p_i = & 0.01 & \text{if } T_{min} = 0.0 \\
 & 0.2 & \text{if } T_{min} = 3.0 \\
 & 1.0 & \text{if } T_{min} = 5.5 \\
 & 1.0 & \text{if } T_{max} = 12.5 \\
 & 0.2 & \text{if } T_{max} = 15.0 \\
 & 0.01 & \text{if } T_{max} = 18.0 \\
 & 0.01 & \text{if } T_{max} = 30.0
\end{array}
$$

where T_{min} (in degrees Celsius) is the minimum water temperature and T_{max} (in degrees Celsius) is the maximum water temperature

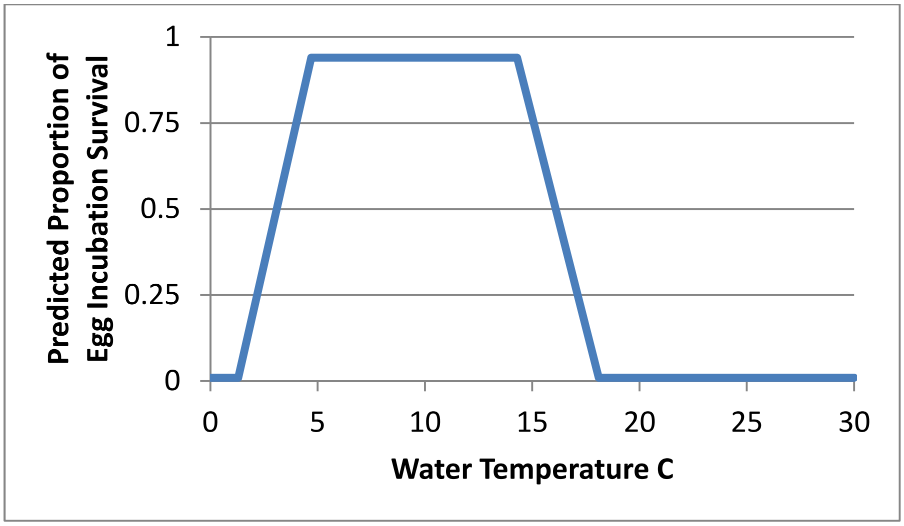


Figure F-8

Functional Relationship between Water Temperature and Coho Salmon Egg Incubation Survival

Continuous or daily long-term temperature data were not available for the Chehalis River. As the best available data set, the monthly water temperature data collected by Ecology's River and Stream Water Quality Monitoring Program (http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html) was used. Ecology has two stations on the mainstem Chehalis River that have been sampled over a long period. The station at Porter (code 23A070, RM33.3) has been sampled monthly since 1959 (except in 1974), and the station at Dryad (code 23A160, RM 97.9) has been sampled monthly in water years 1959 through 1966 and from 1978 to present. In this fish study, temperature data from water years 1978 through 2010 were used.

The minimum and maximum water temperatures observed during each species' egg incubation period were used in the analysis. Among spring Chinook salmon, the analysis was based on water temperatures between September and February. The coho salmon analysis was based on water temperatures between November and January. Temperatures from Ecology's Dryad monitoring station were used in the four reaches upstream of the Newaukum River. Temperatures from Ecology's monitoring station at Porter were applied to the three reaches downstream of the Newaukum River.

In the model calibration period from 1978 through 2010, data from Ecology were used. To estimate annual maximum water temperatures in future years, the model was set to randomly (stochastically) assign a water temperature for a water temperature regime with a normal distribution and a defined mean and standard deviation. This information was calculated using Ecology's data at the Porter and Dryad stations, as well as the predictions from the water quality analysis conducted in this study (see Appendix C of the main report). Using Ecology's data, the first step was to calculate the average and standard deviation of the annual maximum observations over the last 20 years for those months when the adult fish of each species are in the river. For the existing conditions and flood storage only analysis, this information was used as is. For the multi-purpose dam analysis, the estimated changes to water quality were added or subtracted to the average calculated using Ecology's data. This calculation was conducted separately for each study reach, each species, and both dam scenarios. The predicted average temperatures during the egg incubation period are provided in Tables F-31 and F-32.

Table F-31
Maximum Temperatures Predicted During Spring Chinook Salmon Egg Incubation Period

Reach	Maximum and Minimum Temperature (C, ± standard deviation) In Existing and Flood Storage Only Analyses	Maximum and Minimum Temperature (C, ± standard deviation) In Multi-Purpose Dam Analysis	Temperature Difference (C) Between Multi-Purpose Dam and Existing Conditions
Upper Watershed to Proposed Dam Site	13.5 ± 2.2 3.5 ± 1.8	13.5 ± 2.2 3.5 ± 1.8	0.0
Proposed Dam Site to Elk Creek	13.5 ± 2.2 3.5 ± 1.8	14.3 ± 2.2 4.3 ± 1.8	+0.8
Elk Creek to South Fork Chehalis	13.5 ± 2.2 3.5 ± 1.8	14.0 ± 2.2 4.0 ± 1.8	+0.5
South Fork Chehalis to Newaukum River	13.5 ± 2.2 3.5 ± 1.8	13.6 ± 2.2 3.7 ± 1.8	+0.1
Newaukum River to Skookumchuck River	15.1 ± 1.8 4.1 ± 1.0	15.1 ± 1.8 4.1 ± 1.0	+0.1
Skookumchuck River to Black River	15.1 ± 1.8 4.1 ± 1.0	15.1 ± 1.8 4.1 ± 1.0	0.0
Black River to Porter	15.1 ± 1.8 4.1 ± 1.0	15.1 ± 1.8 4.1 ± 1.0	0.0

Note: a) Maximum temperature in the Upper Watershed reach in the multi-purpose analysis was based on the estimated surface water temperature modeled for the reservoir (calculated in Appendix C of the main report).

Table F-32
Maximum Temperatures Predicted During Coho Salmon Egg Incubation Period

Reach	Maximum and Minimum Temperature (C, ± standard deviation) In Existing and Flood Storage Only Analyses	Maximum and Minimum Temperature (C, ± standard deviation) In Multi-Purpose Dam Analysis	Temperature Difference (C) Between Multi-Purpose Dam and Existing Conditions
Upper Watershed to Proposed Dam Site	8.1 ± 1.5 3.5 ± 1.8	8.1 ± 1.5 3.5 ± 1.8	+0.0
Proposed Dam Site to Elk Creek	8.1 ± 1.5 3.5 ± 1.8	7.5 ± 1.5 2.9 ± 1.8	-0.7
Elk Creek to South Fork Chehalis	8.1 ± 1.5 3.5 ± 1.8	7.6 ± 1.5 3.0 ± 1.8	-0.5
South Fork Chehalis to Newaukum River	8.1 ± 1.5 3.5 ± 1.8	8.0 ± 1.5 3.4 ± 1.8	-0.2
Newaukum River to Skookumchuck River	9.0 ± 0.8 4.1 ± 1.0	8.9 ± 0.8 4.0 ± 1.0	-0.1
Skookumchuck River to Black River	9.0 ± 0.8 4.1 ± 1.0	9.0 ± 0.8 4.0 ± 1.0	0.0
Black River to Porter	9.0 ± 0.8 4.1 ± 1.0	9.0 ± 0.8 4.1 ± 1.0	0.0

3.2.5.3 Spring Rearing Survival

The habitat parameters used to estimate spring rearing survival varied among the species. For spring Chinook salmon, juvenile fish survival in the spring was related to the mean water temperatures and a baseline survival rate. For winter steelhead and coho salmon, no parameter limitations on survival during the spring time period were included in the model because including one or more parameters did not affect the models' predictions relative to WDFW estimates used for calibration.

3.2.5.3.1 Mean Water Temperature

Juvenile spring Chinook salmon survival during the spring was related to the mean water temperatures from March through June. This parameter was not used in the winter steelhead or coho salmon models because including the parameter did not improve those models' predictions relative to WDFW estimates used for calibration. The functional relationship developed for Chinook salmon is based on a combination of functional relationships identified in the Habitat Suitability Index report for spring Chinook salmon (Raleigh et al. 1986) and Honea et al. (2009). Raleigh et al. (1986) define a functional relationship in which temperatures were fully suitable between 12 degrees Celsius (°C) and 18°C with linear decline to 0 percent suitability when temperatures reach 0°C and linear increases as temperatures increase to 24°C. Honea et al. (2009) define temperatures as fully suitable ($P_t = 1.0$) when temperatures are less than 17.8°C. The functional relationship used to characterize Chinook fry survival related to water temperature is described in the following function and shown in Figure F-9:

$$p_i = \begin{cases} 1.0 & \text{if } t \leq 18^{o}\text{C} \\ 0.01 & \text{if } t \geq 24^{o}\text{C} \end{cases}$$

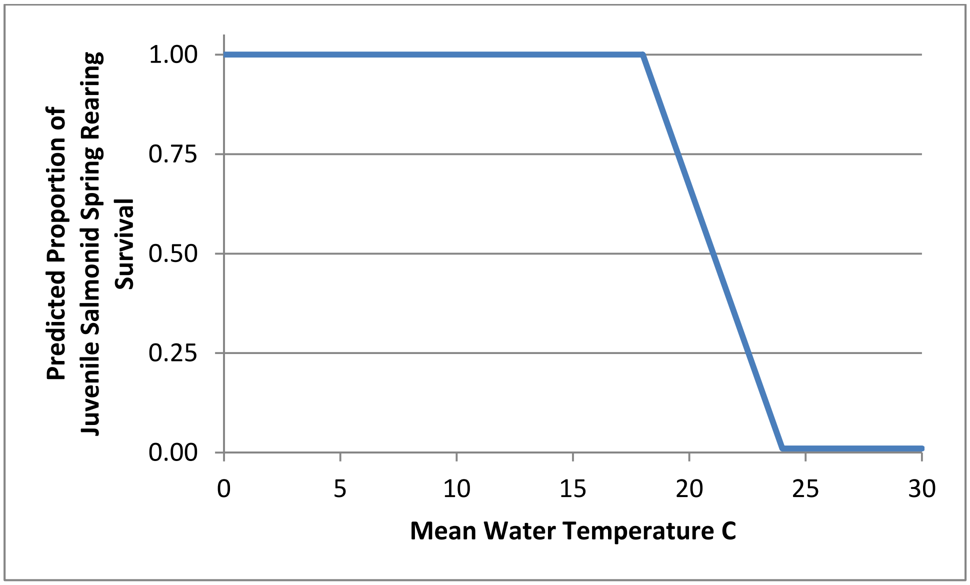


Figure F-9
Functional Relationship between Mean Water Temperature in the Spring and Juvenile Spring Chinook Salmon Survival

In this study, Ecology's monthly temperature data collected at the Dryad and Porter stations for water years 1978 through 2010 were used. The mean water temperatures observed for the months of March through June were used in the model. Temperatures from the Porter station were applied to the Skookumchuck River to Black River and Black River to Porter reaches. Temperatures from the Dryad station were used for all other reaches.

In the model calibration period from 1978 through 2010, the data from Ecology were used. To estimate annual mean water temperatures in future years, the model was set to stochastically assign a water temperature each year using a normal distribution and a defined mean and standard deviation. This information was calculated using Ecology's data at the Porter and Dryad stations, as well as the predictions from the water quality analysis conducted in this study (see Appendix C of the main report). Using Ecology's data, the first step was to calculate the average and standard deviation of the annual mean observations over the last 20 years for those months in which the adult fish of each species are in the river. This information was used as is for the existing conditions and flood storage only analyses. For the multi-purpose dam analysis, the estimated changes to water quality were added or subtracted to the average calculated using Ecology's data. This calculation was conducted separately for each study reach, each species, and both dam scenarios. The predicted average temperatures during the spring rearing period are provided in Table F-33.

Table F-33

Mean Temperatures Predicted During Spring Rearing Period (March through June)

Reach	Mean Temperature (°C, ± standard deviation) In Existing and Flood Storage Only Analyses	Mean Temperature (°C, ± standard deviation) In Multi-Purpose Dam Analysis	Mean Temperature Difference (°C) Between Multi-Purpose Dam and Existing Conditions
Upper Watershed to Proposed Dam Site	11.1 ± 1.7	10.7 ± 1.7	-0.4
Proposed Dam Site to Elk Creek	11.1 ± 1.7	10.7 ± 1.7	-0.4
Elk Creek to South Fork Chehalis	11.1 ± 1.7	10.7 ± 1.7	-0.4
South Fork Chehalis to Newaukum River	11.1 ± 1.7	11.0 ± 1.7	-0.1
Newaukum River to Skookumchuck River	12.5 ± 1.3	12.5 ± 1.3	0.0
Skookumchuck River to Black River	12.5 ± 1.3	12.5 ± 1.3	0.0
Black River to Porter	12.5 ± 1.3	12.5 ± 1.3	0.0

3.2.5.3.2 Baseline Survival Rate

A baseline survival rate of spring Chinook salmon in the spring was applied as a proportion of 0.332. This is the same rate used by Scheuerell et al. (2006) for an analysis of Chinook salmon survival in the Snohomish River, Washington, watershed. No baseline survival rate adjustment was applied to winter steelhead or coho salmon.

3.2.5.4 Summer Rearing Survival

The habitat parameters used to estimate juvenile salmonid survival during the summer varied between the species analyzed. For spring Chinook salmon, juvenile survival during the summer was related to minimum flows, mean water temperature, and a baseline survival rate. For winter steelhead and coho salmon, juvenile survival during the summer was related to minimum flows.

3.2.5.4.1 Minimum Flows

This parameter was not used in the spring Chinook salmon model because including the parameter did not improve this model's predictions relative to WDFW estimates used for calibration. The functional relationship between minimum summer flows and winter steelhead and coho salmon survival was developed based on the Chehalis River work by WDFW. WDFW uses the minimum 60-day average flows between March 1 and November 1 at the USGS gage in Grand Mound as one predictor of coho salmon smolt abundance (Zimmerman 2011). Zimmerman (2011) reported increased numbers of coho smolts with increasing flows based on 10 years of data ranging between 180 and 392 cfs. For this analysis, it was assumed that flows of 392 cfs provide maximum summer survival rates, while flows lower than the analysis range studied by Zimmerman (2011) would continue to decrease linearly ($y – 7907.3x + 46{,}132$). The linear regression formula presented in Zimmerman (2011) was converted to a 0.0 to 1.0 survival based on the number of smolts predicted for a given flow divided by the maximum number of smolts predicted by the formula (at 392 cfs). The resulting relationship between proportion surviving and minimum flows is presented in Figure F-10. Flow data from the hydrology analysis conducted in this study were used (see Appendix A of the main report).

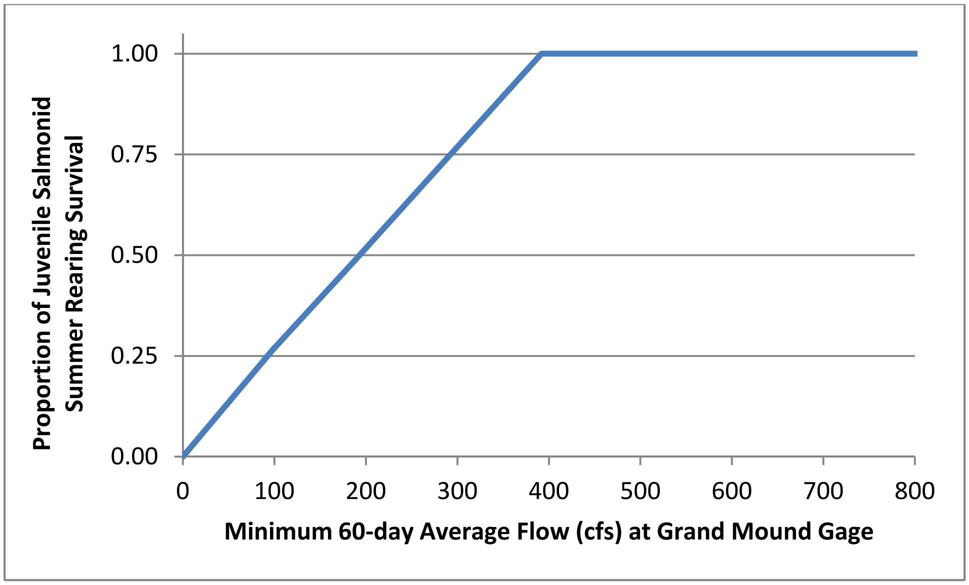


Figure F-10

Functional Relationship between the Minimum 60-day Average Flow at the Grand Mound Gage and Juvenile Salmonid Survival

Flow data from the hydrology analysis conducted in this study were used (see Appendix A of the main report). With the continuation of existing conditions and with a flood storage only dam, the minimum 60-day average flow (mean ± coefficient of variation) at the Grand Mound gage is 262 ± 68 cfs. This is based on data from the last 20 years. In the optimized multi-purpose dam scenario, the minimum 60-day average flow (mean ± coefficient of variation) at the Grand Mound gage is 403 ± 57 cfs.

3.2.5.4.2 Mean Water Temperatures

For spring Chinook salmon, summer rearing survival was related to the mean water temperatures between July and September. This parameter was not used in the steelhead or coho salmon models because it did not improve those models' predictions relative to WDFW estimates used for calibration The data used for this analysis were developed in the same manner as that described for spring rearing survival (Section 3.2.5.3).

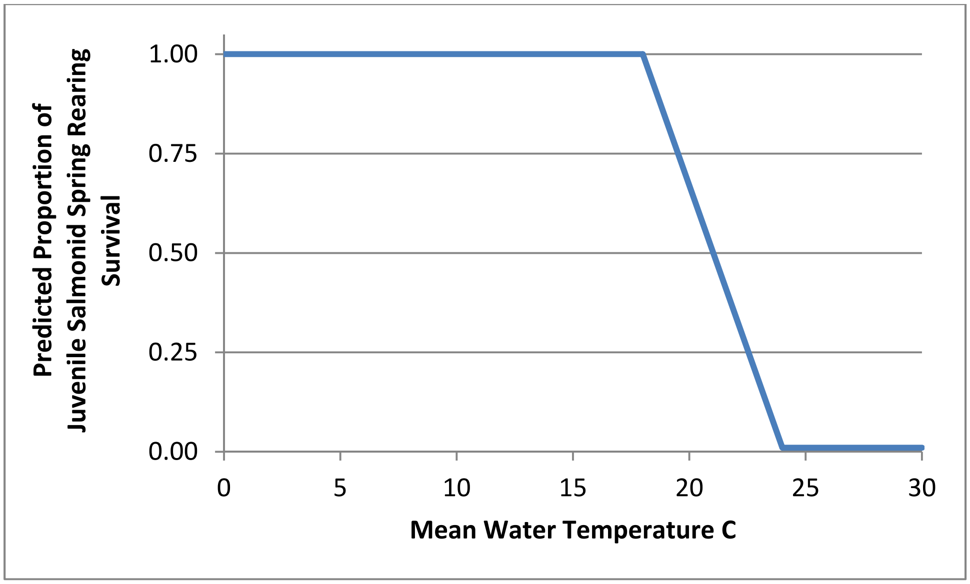


Figure F-11

Functional Relationship between the Mean Summer Water Temperature and Juvenile Salmonid Survival

In this study, Ecology's monthly temperature data collected at the Dryad and Porter stations for water years 1978 through 2010 were used. The mean water temperatures observed for the months of July through September were used in the model. Temperatures from the Porter station were applied to the Skookumchuck River to Black River and Black River to Porter reaches. Temperatures from the Dryad station were used for all all other reaches.

In the model calibration period from 1978 through 2010, the data from Ecology were used. To estimate annual mean water temperatures in future years, the model was set to stochastically assign a water temperature for each year with a normal distribution and a defined mean and standard deviation. This information was calculated using Ecology's data at the Porter and Dryad stations, as well as the predictions from the water quality analysis conducted in this study (see Appendix C of the main report). Using Ecology's data, the first step was to calculate the average and standard deviation of the annual mean observations over the last 20 years for those months when the adult fish of each species are in the river. This information was used as is for the existing conditions and flood storage only analyses. For the multi-purpose dam analysis, the estimated changes to water quality were added or subtracted to the average calculated using Ecology's data. This calculation was conducted separately for each study reach, each species, and both dam scenarios. The predicted average temperatures during the summer rearing period are provided in Table F-34.

Table F-34
Mean Temperatures Predicted During Summer Rearing Period (March through June)

Reach	Mean Temperature (°C, ± standard deviation) In Existing and Flood Storage Only Analyses	Mean Temperature (°C, ± standard deviation) In Multi-Purpose Dam Analysis	Mean Temperature Difference (°C) Between Multi-Purpose Dam and Existing Conditions
Upper Watershed to Proposed Dam Site	16.9 ± 1.8	12.4 ± 1.8	-4.5
Proposed Dam Site to Elk Creek	16.9 ± 1.8	12.4 ± 1.8	-4.5
Elk Creek to South Fork Chehalis	16.9 ± 1.8	14.3 ± 1.8	-2.6
South Fork Chehalis to Newaukum River	16.9 ± 1.8	16.3 ± 1.8	-0.6
Newaukum River to Skookumchuck River	18.0 ± 1.4	17.8 ± 1.4	-0.2
Skookumchuck River to Black River	18.0 ± 1.4	17.9 ± 1.4	-0.1
Black River to Porter	18.0 ± 1.4	18.0 ± 1.4	+0.0

3.2.5.5 Overwinter Rearing Survival

A baseline survival rate was applied as a proportion of 0.8 for spring Chinook, winter steelhead, and coho salmon. No other productivity parameter was applied to the overwinter rearing survival.

3.2.5.6 Smolt-to-Adult Survival

Smolt-to-adult survival rates were used to characterize fish survival from smolt outmigration until adult return. Sharma (2009) reported data on Chinook salmon from the Queets River surviving from smolts to age-2 between approximately 0.5 and 4.5 percent for the years 1978 through 2004. Similar marine survival to age-2 rates were reported for several west coast stocks ranging from California to Alaska (Sharma 2009). In an examination of coho marine survival, Beetz (2009) reported the marine survival of coho salmon from Washington coastal rivers as ranging between approximately 0.7 and 7 percent for the years 1970 through 2004. Among wild winter steelhead from the Queets River, Cramer and Beamesderfer (2006) report marine survival rates ranging between 7.7 and 17.7 percent for the years 1984 through 1995. Of the wild steelhead data presented, the Queets had the highest average smolt-to-adult survival rates, although the Keogh River on northern Vancouver Island, British Columbia, had a period of higher rates (average of 15.5 percent between 1977 and 1989) followed by a period of lower rates (less than 4 percent between 1990 and the end of the study data in 1994), which brought the overall average down. The Keogh River data provide a stark example of how conditions in the marine environment contribute to varying patterns of marine survival. For the purposes of this study, the available data on marine survival between 1978 and 2010 were used in the model calibration. For the models predicting salmonid population growth related to the construction and operation of a dam, standardized rates were used for all three species analyzed. This approach was taken because coho and Chinook salmon survival rates were found to be in nearly the same range in the studies identified, while the high survival rates of steelhead were more than 15 years old, and there is evidence from other watersheds that their survival rate should be transferred into a lower survival rate pattern. A benefit of this approach was to provide a standardized input to the life-cycle survival; therefore, any differences in survival can be attributed to the freshwater conditions input to the model. For this analysis, the smolt-to-adult survival rate was input to range between 0.5 and 5 percent.

3.3 Model Calibration

The models were calibrated to salmonid population abundance estimates provided by WDFW. The WDFW estimates were based on annual spawning ground surveys in index reach that were then extrapolated to estimate the population abundance. Calibration included testing multiple iterations of functional relationship combinations to determine which productivity parameters appeared to be the best predictors. Criteria for selection were based on determining functional relationship combinations that produced results most similar to the WDFW estimates. This process resulted in different combinations of functional relationships applied to the three species (as described in Section 3.2.5). In calibrating the model, the modeled results were compared to WDFW estimates to examine:

- Whether the model predictions of spawner abundance were in the same approximate

range as that documented in the WDFW estimates
- Whether the model tracked increases or decreases between years (i.e., relative inter-annual trends) in a similar pattern to those estimated by WDFW

3.4 Sensitivity Analyses

Many of the habitat parameters affecting the survival of individual salmonids from one life stage to the next vary over time. In the models developed for each species, the model inputs to characterize habitat parameters can vary from one year to the next. For the calibration of the models presented in the preceding sections, habitat parameter entries between the model start date (1978) and the last year of data (2010) were based on documented observations in the basin, to the extent possible. Based on the mean, range, and/or variability of these parameters, estimates of each parameter's condition in future years were input to the model either as a set value or as a random variable that varies according to a user-specified range or distribution. For the purposes of preparing "most likely" future estimates, the model inputs for each habitat parameter were based on the best available data of the last 20 years. As evident in the results provided in subsequent sections, this approach is useful for examining the predicted differences between no dam and each of the dam scenarios.

In order to build on the understanding of the general differences and predicted trends of each scenario, additional model scenarios were run to examine whether additional population impacts or vulnerability were evident if conditions occurred outside the identified range used for the various habitat parameters. This sensitivity analysis examined salmonid spawner abundance if less favorable habitat conditions occurred in the basin. These less favorable conditions are realistic given the uncertainty of predicting future habitat conditions, as well as the likelihood of changing conditions (e.g., climate change, decadal regime shifts, El Niño, La Niña) over the 50-year simulation period.

Sensitivity analyses were conducted for the no dam scenario and the multi-purpose dam with water releases from the bottom of the reservoir and fish passage provided. The analyses investigated the effects of different assumptions for five different habitat parameter change combinations compared to those used in the calibrated models:

- Intermittent high-flow events comparable to the historical hydrograph
- Water temperatures increased by 2°C
- Smolt-to-adult survival reduced to be between 0.5 and 2.5 percent instead of the 0.5 to 5.0 percent range used in the base model
- Habitat degradation with a dam in place occurring more rapidly, at 1 percent per year
- All four of the above changes in one combined scenario

4 RESULTS

4.1 Model Calibration

Base models were developed for all three salmonid species employing an iterative process involving a variety of combinations of environmental data with a documented link to salmonid survival. For each species, the combination of parameters described in Section 3 provided the closest estimates for numbers of adult spawners compared to the WDFW estimates, and the resulting models served as the calibrated version.

The numbers of spring Chinook salmon adults spawning in the study area predicted by the model and those estimated by WDFW from 1991 to 2010 were compared (Figure F-12). The range in the predicted number of annual spawners was similar to the WDFW estimates in all years except 2005, when the model prediction was higher than the WDFW estimate. Trends in abundance across the modeled period were somewhat similar with no clear pattern of one approach producing estimated numbers of adult spawners that were above or below the other. However, variability between the two outputs was high, and regressing the model predictions and WDFW estimates indicated the model only accounted for 14 percent of the variability in the WDFW estimates ($r^2 = 0.14$). Reasons for the low correlation between the two methods used to estimate the number of spring Chinook salmon adults spawning in the study area (predicted by the model and estimated by WDFW) from 1991 to 2010 are unknown. While both approaches produced estimates of similar ranges and trends over time, the low correlation between outputs from the two methods may have resulted from their using different input parameters, a lack of environmental data for a habitat parameter that significantly influences spring Chinook survival, or an inaccuracy in a habitat parameter input or functional relationship.

The winter steelhead model and WDFW's estimated number of winter steelhead spawners are presented in Figure F-13. WDFW data on the number of steelhead spawners were available between 1996 and 2010, excluding 2009 because a storm event prevented upper watershed spawner surveys. The calibrated model produced spawner estimates that were in the same range as WDFW estimates. The modeled increase or decrease in the predicted number of spawners from one year to the next matched the inter-annual trend observed by WDFW in 8 of 12 analysis periods, including 8 of the last 10. A regression of the model's prediction of the number of spawners compared to the WDFW estimates indicated that the model accounted for 89 percent of the variability in the WDFW estimates ($r^2 = 0.89$).

The coho salmon model and WDFW's estimated number of coho salmon spawners are presented in Figure F-14. WDFW data on the number of coho salmon spawners were available between 1998 and 2007. The calibrated model produced spawner estimates that were in the same range as WDFW estimates. The modeled increase or decrease in the predicted number of spawners from one year to the next matched the inter-annual trend observed by WDFW in 7 of 9 analysis periods. A regression of the model's prediction of the number of spawners compared to the WDFW estimates indicated that the model accounted for 49 percent of the variability in the WDFW estimates ($r^2 = 0.49$).

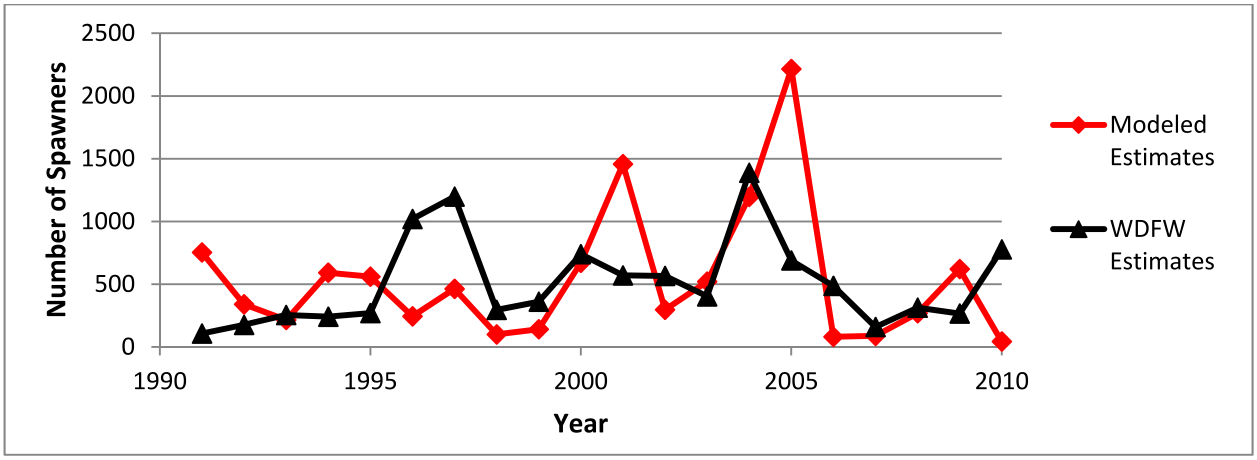


Figure F-12

Number of Spring Chinook Salmon Spawners as Predicted by the Base Model and WDFW Estimates of Mainstem Chehalis Spawners

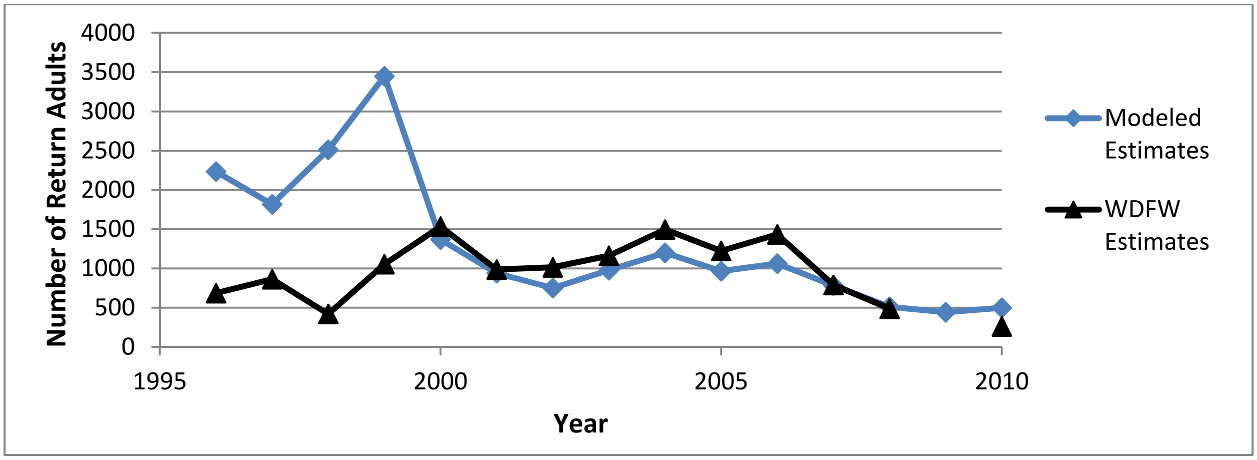


Figure F-13

Number of Winter Steelhead Spawners as Predicted by the Base Model and WDFW Estimates of Mainstem Chehalis Spawners

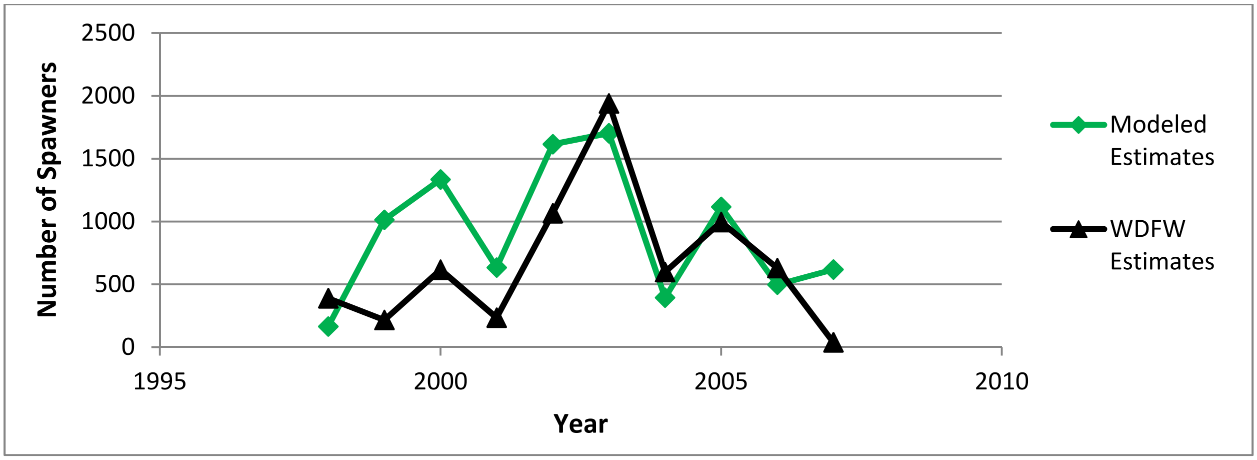


Figure F-14

Number of Coho Salmon Spawners as Predicted by the Base Model and WDFW Estimates of Mainstem Chehalis Spawners

4.2 Salmonid Population Estimates Assuming Continued Existing Conditions

Twenty 50-year simulations were run of the calibrated model for each species to estimate the future salmonid population sizes assuming existing conditions continued into the future. The existing conditions model assumed that no dam was constructed and recent documented conditions for each of the productivity parameters and capacity estimates continued throughout the period of analysis.

The estimation of future population abundance incorporated several habitat parameters that vary year-to-year in the model. As a result, the expression of each habitat parameter varied between model simulations and the resulting estimate of the fish population size varied accordingly based on the functional relationships identified in Section 3. In the presentation of the predicted number of salmonid spawners assuming continued existing conditions, as well as in subsequent sections presenting the modeled results with dams, an identical graphical format was used. Using winter steelhead model results as an example, the twenty 50-year simulations under existing conditions yields a predicted future abundance that varies by nearly a factor of 10 (see Figure F-15). The model simulations predict identical winter steelhead spawner abundance through 2010, the last year of empirical habitat data (e.g., water temperature) included in the model; therefore, the model outputs through 2010 appear as one line in the figure.

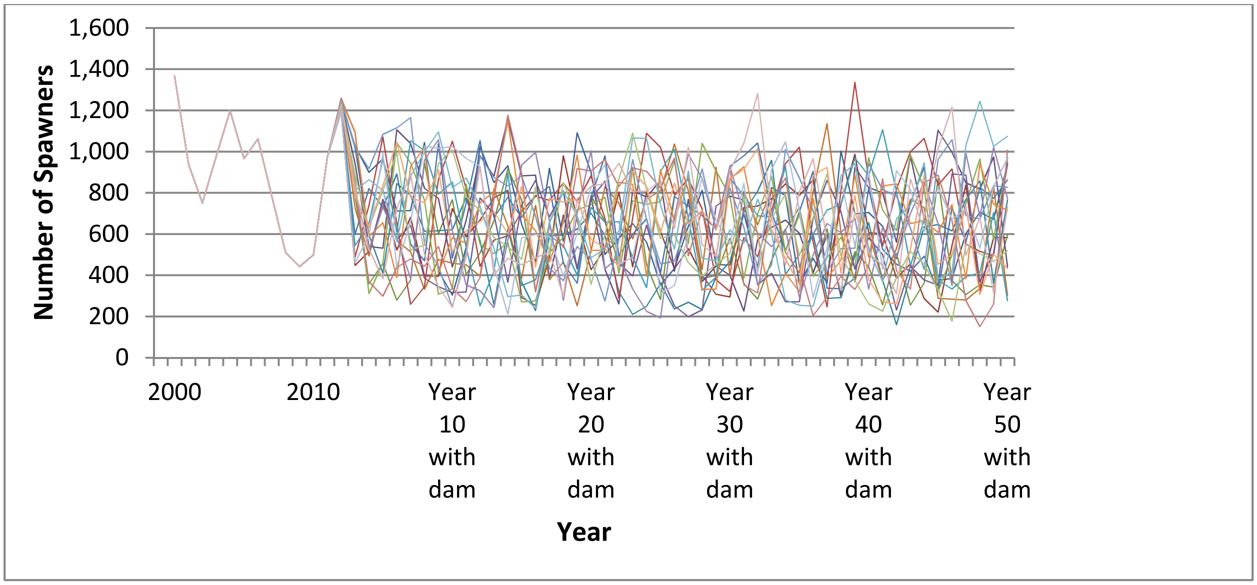


Figure F-15

Example of Simulations Predicting Winter Steelhead Spawners Assuming the Continuation of Existing Conditions

In order to present these model results in a more concise and understandable fashion, figures depicting future fish population estimates show the median number of fish predicted each year in the twenty simulations, as shown in Figure F-16 for winter steelhead spawners.

Thus, the line connecting the modeled medians during each year in the 50-year simulation period reflects less year-to-year variability than is apparent in any of the individual simulations. In order to present an indication of the variability among simulations, the figure also shows the modeled range, which is the range between the highest and lowest estimates each year. The minimum values in the range are particularly informative because the lowest numbers suggests the vulnerability of the fish population given the model inputs.

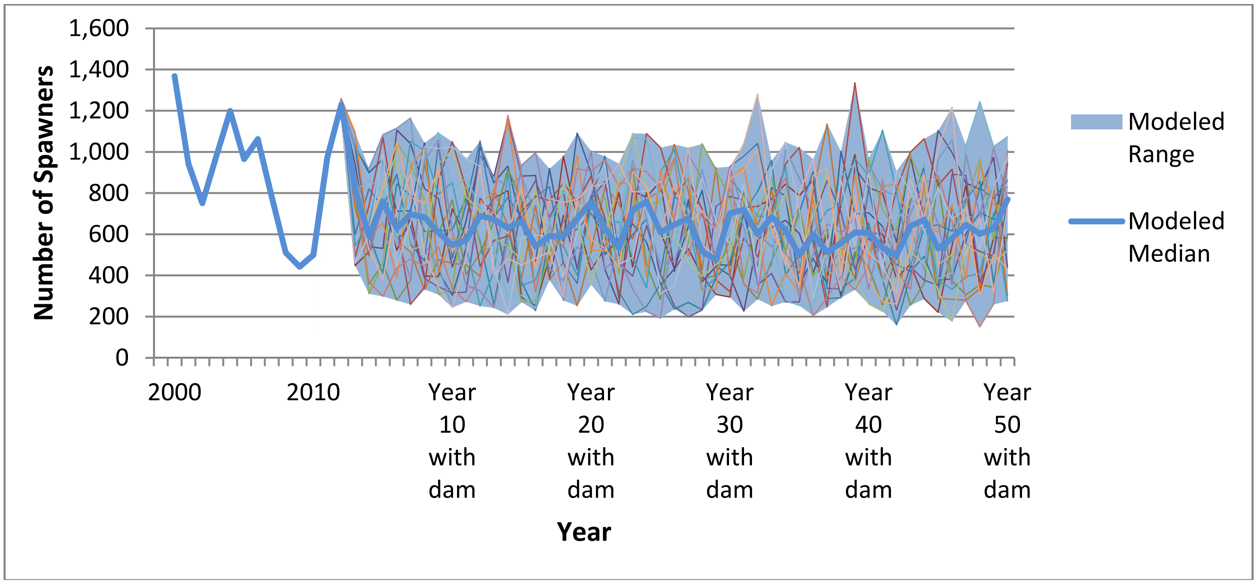


Figure F-16

Example of Modeled Average and Modeled Range Graphical Presentation Used to Present Results of Simulations Predicting Winter Steelhead Spawners Assuming Existing Conditions

The median predicted number of spring Chinook salmon spawners assuming the continuation of existing conditions increased steadily over the 50-year simulation period (Figure F-17). The highest single year median estimate was 1,324 spring Chinook spawners, which is similar to the highest estimated number of spawners reported by WDFW (1,388) provided between 2001 and 2010. After approximately Year 25 with a dam, a substantial amount of variability occured among the simulation estimates, with the maximum estimated number of spawners rangeing as high as 9,124 and as low as 3. The minimum number of spring Chinook spawners predicted was fewer than 100 in 46 of the 50 years analyzed.

The median predicted number of winter steelhead spawners assuming the continuation of existing conditions was similar to the recent WDFW estimates (Figure F-18). The modeled median of each year, assuming continuation of existing conditions, was typically between 500 and 750 winter steelhead spawners. A fairly uniform range between the highest and lowest estimated number of spawners each year was predicted throughout the 50-year simulation period. The minimum estimated number of winter steelhead spawners generally varied between 200 and 300 per year, which is similar to the lowest estimate (262) in the 2001 to 2010 database provided by WDFW. The maximum numbers of predicted steelhead spawners estimates were generally between 900 and 1,200 fish, which is not as high as the highest WDFW estimate (1,534) documented in recent years.

The median predicted numbers of coho salmon spawners, assuming the continuation of existing conditions, were in a similar range with similar year-to-year variability as recent WDFW estimates (Figure F-19). The modeled median did not reflect the year-to-year variability that can be expected. The modeled median was typically between 500 and 800 coho spawners. Minimum coho spawner numbers were predicted to generally range between 100 and 300 fish, although fewer than 100 fish were predicted in 6 of the 50 post-dam years analyzed.

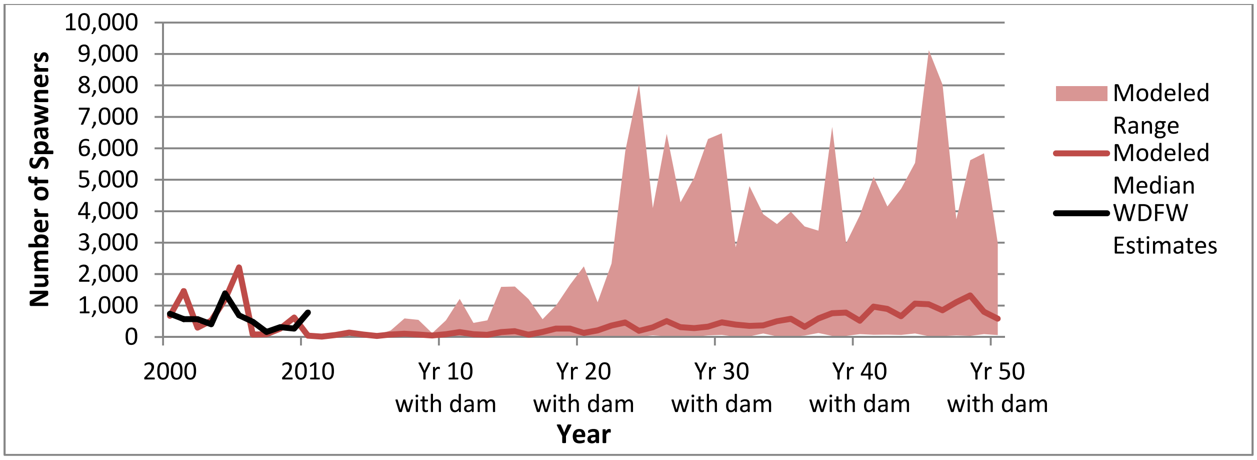


Figure F-17

Predicted Number of Spring Chinook Salmon Spawners Assuming the Continuation of Existing Conditions

Note: Although this figure depicts model estimates without a dam, the results are presented in terms of "year with dam" in order to facilitate comparison with dam results presented in other figures which assume a dam is constructed in 2011. Also, the bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

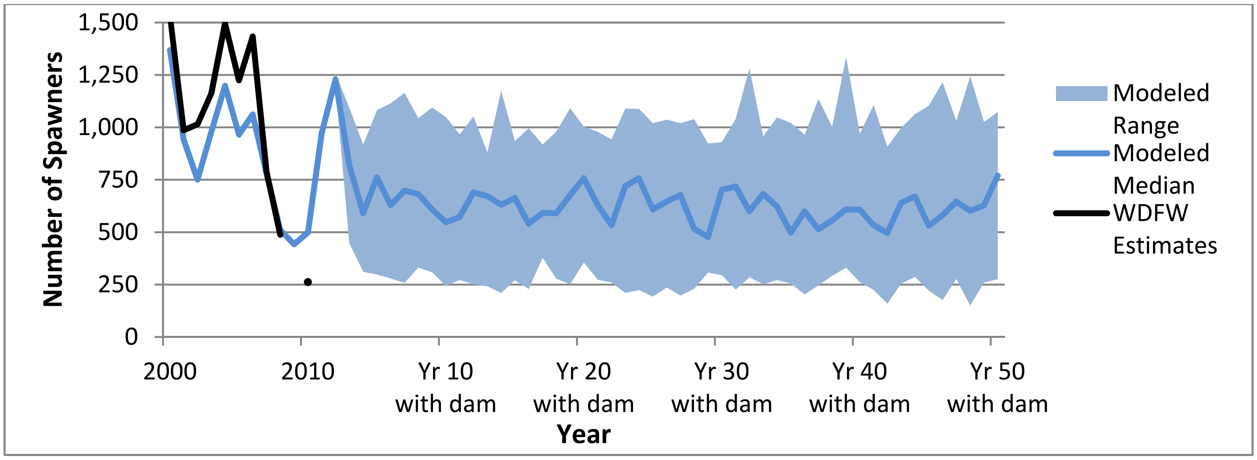


Figure F-18

Predicted Number of Winter Steelhead Spawners Assuming the Continuation of Existing Conditions

Note: Although this figure depicts model estimates without a dam, the results are presented in terms of "year with dam" in order to facilitate comparison with dam results presented in other figures. Also, the bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

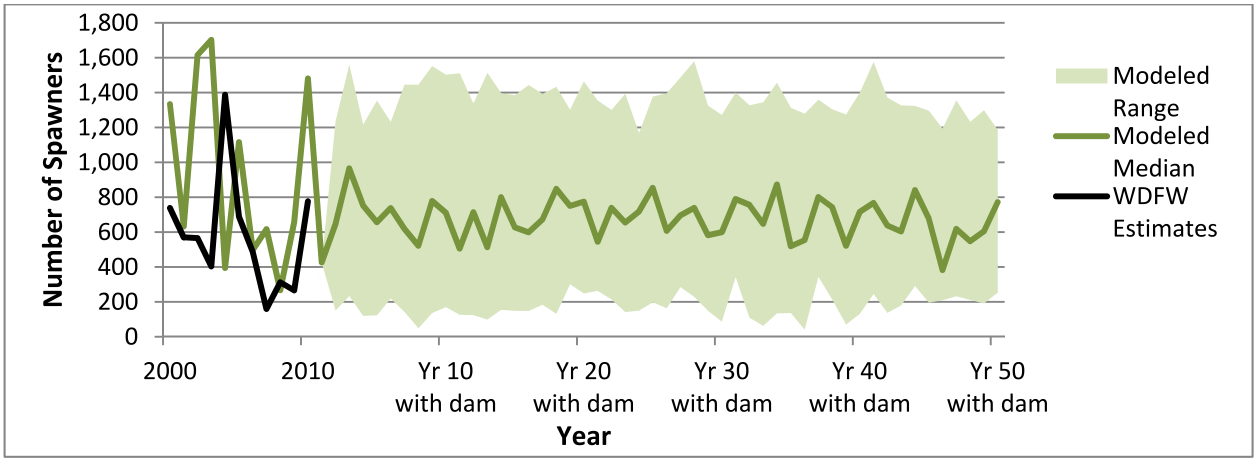


Figure F-19

Predicted Number of Coho Salmon Spawners Assuming the Continuation of Existing Conditions

Note: Although this figure depicts model estimates without a dam, the results are presented in terms of "year with dam" in order to facilitate comparison with dam results presented in other figures. Also, the bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

4.3 Flood Storage Only Dam Scenarios

Salmonid population numbers with the construction and operation of a flood storage dam were evaluated with three fish survival scenarios past the dam and reservoir. These scenarios were analyzed because of the unpredictability in achieving target fish passage survival rates through a reservoir and dam. As described in Section 3.2.3.4, the fish passage survival rates in the three scenarios are:

- Target: 80 percent juvenile and 95 percent adults for all three species
- Poor: 23 percent juvenile spring Chinook salmon, 49 percent juvenile winter steelhead, and 32 percent juvenile coho salmon; 80 percent adults
- No: 0 percent juvenile and 0 percent adults for all three species

As described for continued existing conditions (see Section 4.2), the twenty model simulations run for each scenario are presented using the modeled annual median and range predicted for each year.

4.3.1 Spring Chinook Salmon

With the construction and operation of a flood storage only dam that provides upstream and downstream fish passage, the number of spring Chinook spawners is predicted to be low but steady throughout the 50-year simulation period (see Figure F-20). Assuming target survival rates past the dam are achieved, the predicted median number of spawners each year typically ranged between 100 and 300 fish. In both the poor survival and no survival scenarios, the predicted median numbers typically ranged between 50 and 200 fish each year.

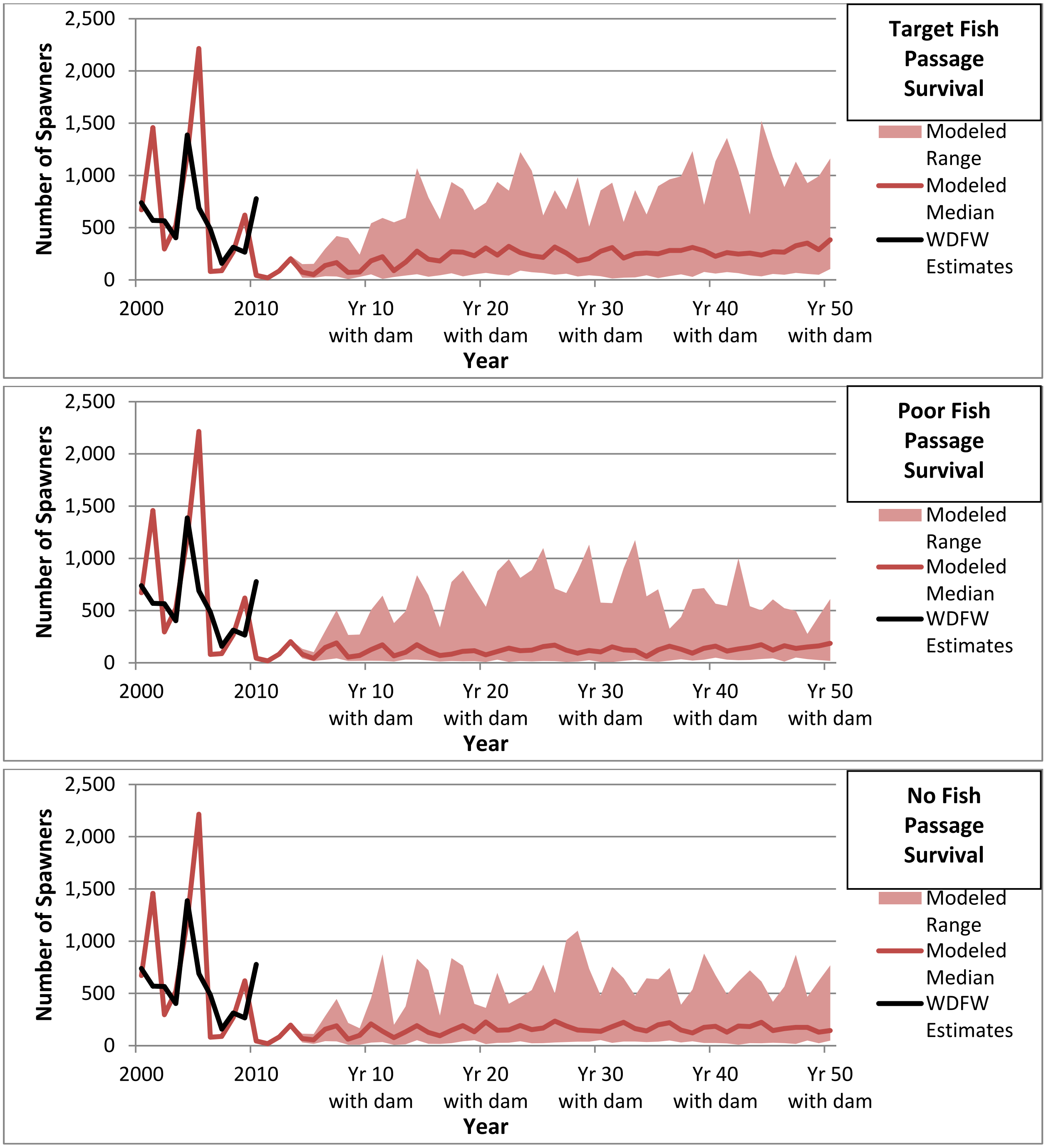


Figure F-20

Predicted Number of Spring Chinook Salmon Spawners In Three Fish Passage Scenarios With A Flood Storage Only Dam

Note: The bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

While the predicted median numbers could be interpreted to predict a smaller, but stable, spring Chinook population compared to the spawner number estimates if existing conditions continued (see Figure F-17), the minimum number of spawners each year suggests the potential for low spring Chinook salmon returns with a flood storage only dam. Assuming target survival rates past the dam, the predicted minimum number of spawners each year was fewer than 50 fish in 26 out the 50 years. In the poor and no survival scenarios, the predicted minimum number of spawners each year was fewer than 50 fish for more than 40 of the 50 years, but did not decline to zero fish.

In all three fish passage survival scenarios with a flood storage only dam, the predicted maximum number of spawners each year was in the low to middle range of the WDFW estimates used in the model calibration.

In combination, these results indicate that a flood storage only dam would substantially reduce the number of spring Chinook spawners each year, and if target fish passage survival rates cannot be achieved, then an even more substantial reduction in numbers of fish was predicted.

4.3.2 Winter Steelhead

With the construction and operation of a flood storage only dam that provides upstream and downstream fish passage, the number of winter steelhead spawners was predicted to be low but steady throughout the 50-year simulation (see Figure F-21). Assuming target survival rates past the dam are achieved, the predicted median number of spawners each year typically ranged between 250 and 500 fish. In the poor fish passage survival scenario, the predicted median numbers of winter steelhead spawners each year were reduced further to 175 to 300 fish. In the no fish passage survival scenario, the predicted median numbers of winter steelhead spawners each year typically ranged between 50 and 200 fish.

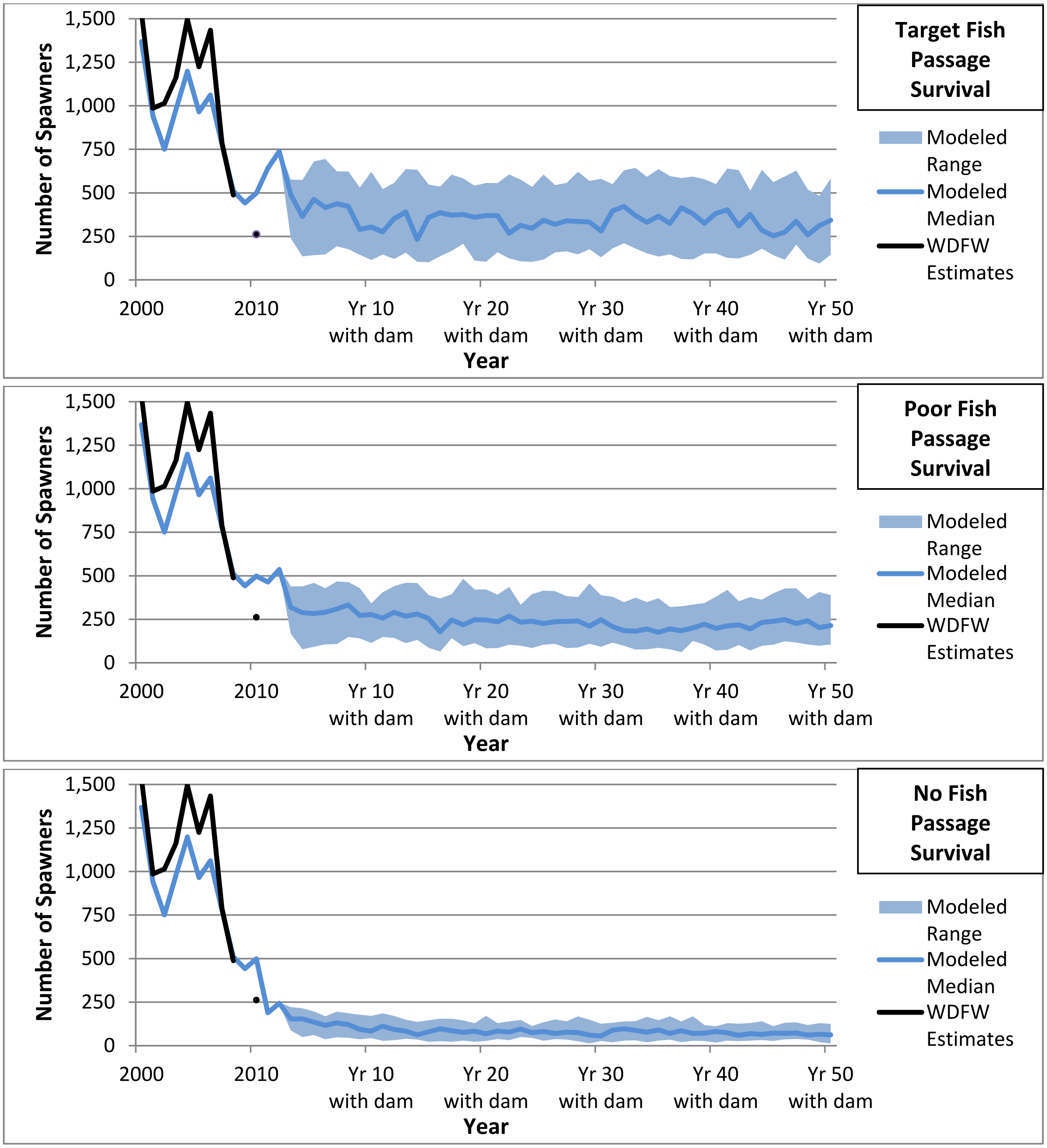


Figure F-21

Predicted Number of Winter Steelhead Spawners In Three Fish Passage Scenarios With A Flood Storage Only Dam

Note: The bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

While the predicted median numbers could be interpreted to predict a smaller, but stable, winter steelhead population compared to the spawner number estimates if existing conditions continued (see Figure F-18), the minimum number of spawners each year suggests the potential for some low winter steelhead salmon returns with a flood storage dam. Assuming target survival rates past the dam, the predicted minimum number of spawners each year was fewer than 100 fish in only 1 out the 50 years, as annual minimum numbers typically ranged between 100 and 200 fish. In the poor fish passage survival scenario, the minimum number of spawners predicted each year was fewer than 100 in 23 out of the 50 years analyzed. The numbers were even lower in the no fish passage survival scenario, in which the minimum number of spawners predicted each year was fewer than 100 in 23 out of the 50 years, including 44 years with fewer than 50 spawners predicted. None of the scenarios predicted zero spawners in any of the simulations.

In all three fish passage survival scenarios with a flood storage only dam, the predicted maximum number of winter steelhead spawners each year was at or below the lowest number of spawners reported in the WDFW estimates used in the model calibration. In fact, in the no fish passage survival scenario, fewer winter steelhead spawners each year were predicted than in any of the annual WDFW estimates used in the model calibration.

In combination, these results indicate that a flood storage only dam would substantially reduce the number of winter steelhead spawners each year, and if target fish passage survival rates cannot be achieved, then an even more significant reduction in numbers of fish was predicted, especially if no fish passage survival occurs.

4.3.3 Coho Salmon

With the construction and operation of a flood storage only dam that provides upstream and downstream fish passage, the number of coho salmon spawners is predicted to be low but steady throughout the 50-year simulation period (see Figure F-22). Assuming target survival rates past the dam were achieved, the predicted median number of spawners each year typically ranged between 250 and 500 fish. In the poor fish passage survival scenario, the predicted median numbers of coho salmon spawners each year were reduced further to 200 to 325 fish. In the no fish passage survival scenario, the predicted median numbers of coho salmon spawners each year typically ranged between 100 and 200 fish.

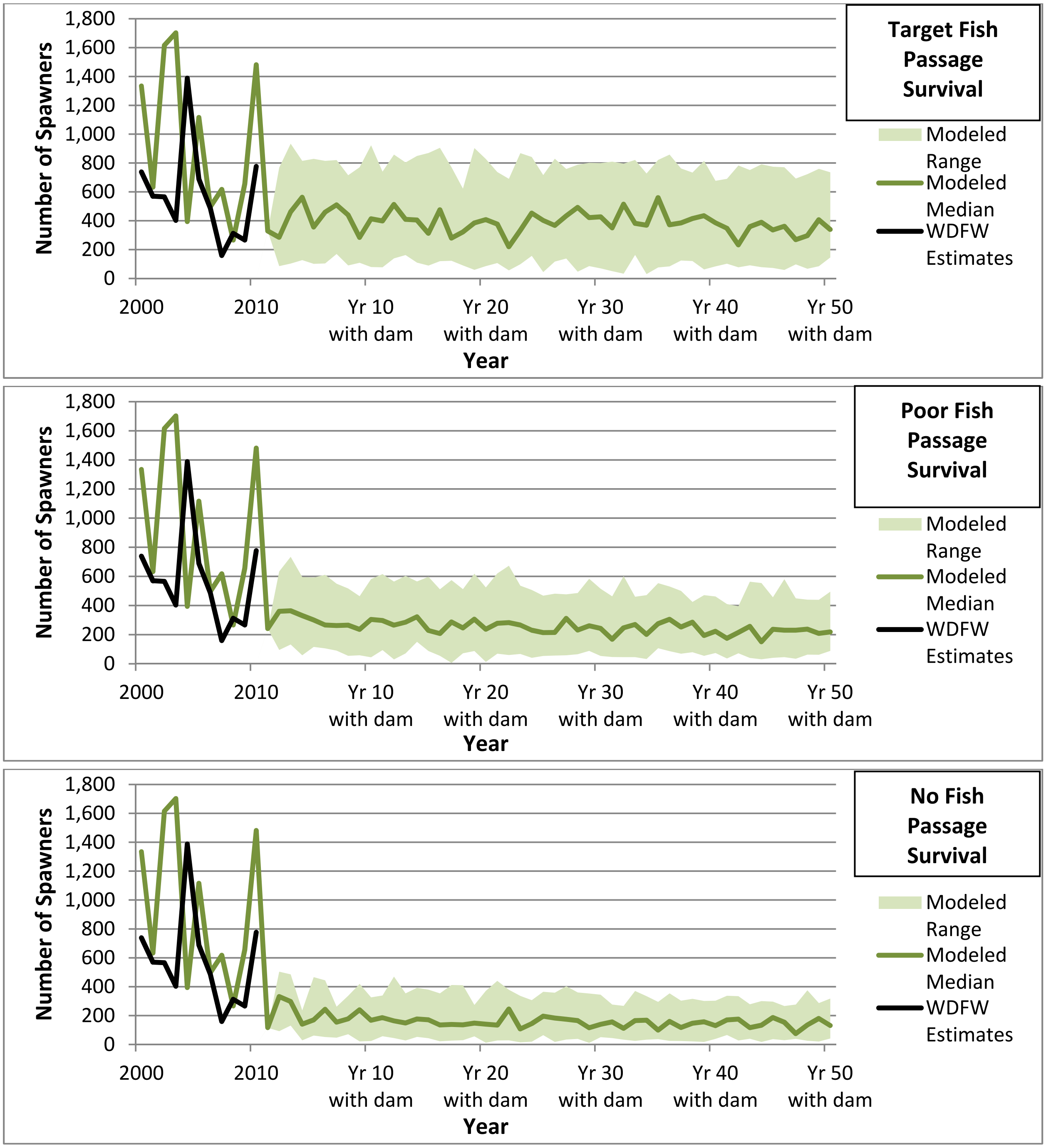


Figure F-22

Predicted Number of Coho Salmon Spawners In Three Fish Passage Scenarios With A Flood Storage Only Dam

Note: The bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

While the predicted median numbers could be interpreted to predict a smaller, but stable, coho salmon population compared to the spawner number estimates if existing conditions continued (see Figure F-19), the minimum number of spawners each year is an informative indicator of the potential for some low coho salmon returns with a flood storage only dam. Assuming target survival rates past the dam, the predicted minimum number of spawners each year was fewer than 100 fish in 29 out the 50 years. In the poor fish passage survival scenario, the minimum number of spawners predicted each year was fewer than 100 in 44 out of the 50 years analyzed, including 15 years with fewer than 50 spawners predicted. The numbers were even lower in the no fish passage survival scenario, in which the minimum number of spawners predicted each year was fewer than 100 in 48 out of the 50 years, including 38 years with fewer than 50 spawners predicted. None of the scenarios predicted zero spawners in any of the simulations.

Assuming target fish survival rates past the dam, the predicted maximum number of coho salmon spawners each year was in the middle of the range of the WDFW estimates used in the model calibration. In the poor fish passage scenario, the predicted maximum numbers were in the low to middle range of the WDFW estimates used in the model calibration. In the no fish passage survival scenario, the predicted maximum numbers of coho salmon spawners were among the lowest of annual WDFW estimates used in the model calibration.

4.4 Multi-Purpose Dam Scenarios

With the continued presence of an impounded reservoir with a multi-purpose dam, water could be released to provide more salmonid habitat and reduce high water temperatures in some parts of the river during summer months. As described in Section 3.2.4.3, the fish population impacts with a multi-purpose dam were investigated assuming water is released from the bottom of the reservoir on a release schedule to maximize fish habitat given the amount of water available in the reservoir. Consistent with the flood storage only analysis, the multi-purpose dam analyses were conducted assuming three fish passage survival scenarios (see Section 3.2.3): target survival, poor survival, and no survival. These scenarios were analyzed because of the unpredictability in achieving target fish passage survival rates through a reservoir and dam.

4.4.1 Spring Chinook Salmon

With the construction and operation of an “optimized multi-purpose dam” that provides upstream and downstream fish passage, the number of spring Chinook salmon spawners was predicted to steadily increase over the first 30 years with a dam, then become more stable over the remaining 20 years analyzed (see Figure F-23). Assuming target survival rates past the dam are achieved, the predicted median number of spawners increased from 104 fish in the first 10 years with a dam to approximately 1,000 spawners by Year 30 with a dam. The predicted median number of spring Chinook salmon spawners in the last 20 years of the analysis assuming target fish passage survival was 1,092 spawners. The predicted numbers of spawners in the last 20 years of the analysis assuming poor or no fish passage survival were very similar (1,056 and 1,034, respectively). These numbers are close to the highest estimated number of spring Chinook spawners in the WDFW estimates used in the calibration of the model.

In all three fish passage survival scenarios analyzed with an optimized multi-purpose dam, the predicted minimum number of spring Chinook salmon spawners each year increased in a similar trend as seen in the predicted median numbers: low in first 10 years with dam, increases until approximately year 30, then fairly steady production for the remaining 20 years of the simulation. In all three fish passage scenarios, the predicted minimum number of spring Chinook salmon spawners each year was typically 400 to 500 fish during the last 20 years. However, in all three fish passage scenarios, the predicted number of spring Chinook salmon spawners was lower than 50 fish for 5 or more of the first 10 years with a dam.

As described for the median and minimum numbers, the predicted maximum numbers are low during the first 10 years and increasing throughout the first 30 years with a dam. In all three fish passage survival scenarios analyzed with an optimized multi-purpose dam, the predicted maximum number of spring Chinook salmon spawners each year was equal to or higher than the highest of the WDFW estimates used in the model calibration by year 30.

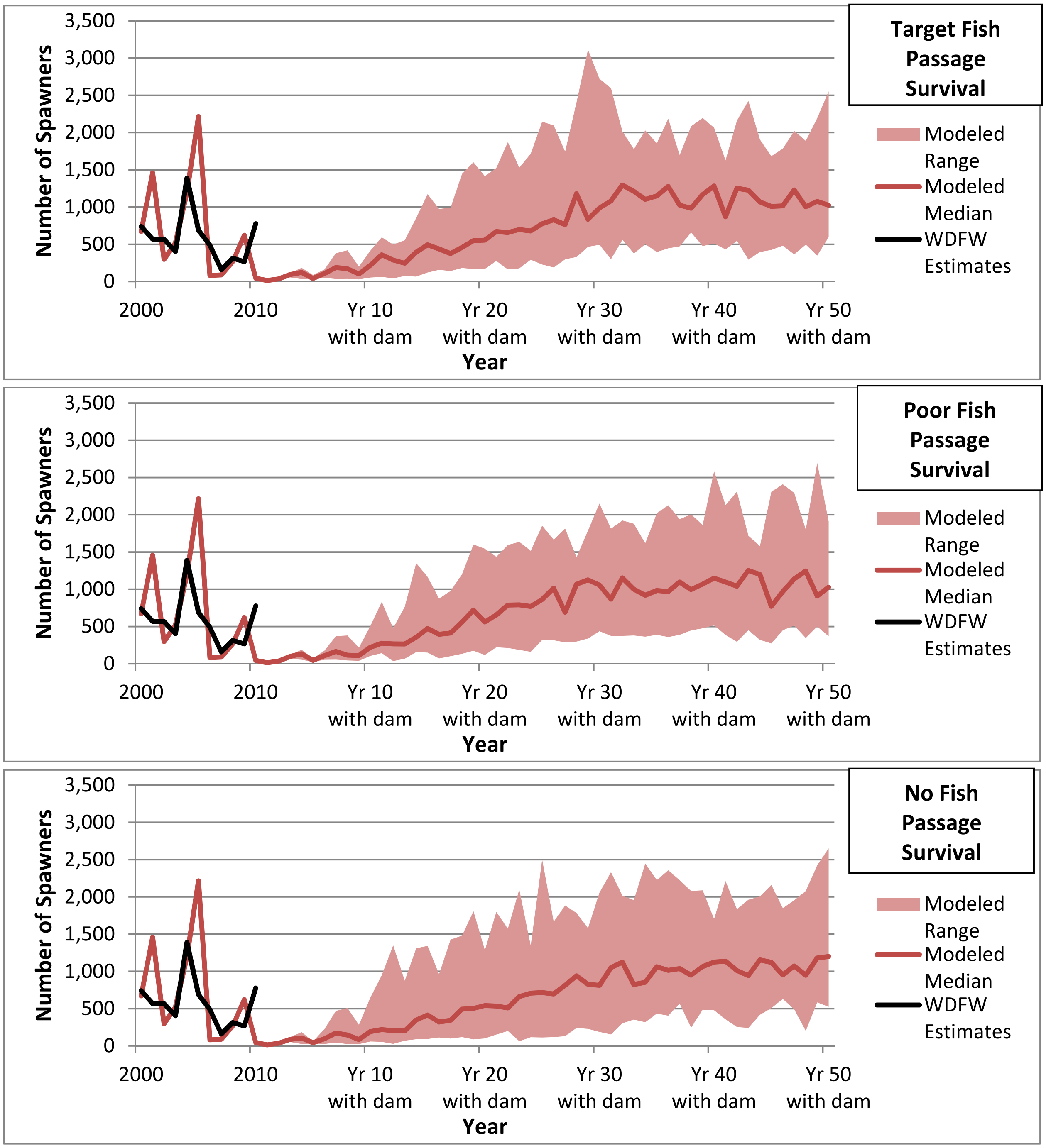


Figure F-23

Predicted Number of Spring Chinook Salmon Spawners In Three Fish Passage Scenarios With An Optimized Multi-Purpose Dam

Note: The bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

4.4.2 Winter Steelhead

With the construction and operation of an optimized multi-purpose dam that provides upstream and downstream fish passage, the number of winter steelhead spawners was predicted to be low but steady throughout the 50-year simulation period (see Figure F-24). Assuming target survival rates past the dam are achieved, the predicted median number of spawners each year typically ranged between 350 and 500 fish. In the poor fish passage survival scenario, the predicted median numbers of winter steelhead spawners each year were reduced further to 250 to 400 fish. In the no fish passage survival scenario, the predicted median numbers of winter steelhead spawners each year typically ranged between 100 and 150 fish each year.

While the predicted median numbers could be interpreted to predict a smaller, but stable, winter steelhead population compared to the spawner number estimates if existing conditions continued (see Figure F-18), the minimum number of spawners each year suggests the potential for some low winter steelhead returns with an optimized multi-purpose dam. Assuming target survival rates past the dam, the predicted minimum number of spawners each year typically ranged from 125 to 250 fish. In the poor fish passage survival scenario, the minimum number of spawners predicted each year typically ranged from 90 to 150 fish with fewer than 100 fish predicted in 10 out of the 50 years analyzed. The numbers are even lower in the no fish passage survival scenario, in which the minimum number of spawners predicted each year was fewer than 100 in 48 out of the 50 years, including 29 years with fewer than 50 spawners predicted.

Assuming target fish survival rates past the dam, the predicted maximum number of winter steelhead spawners each year was at the lower end of the range of the WDFW estimates used in the model calibration. In the poor fish passage scenario, the predicted maximum numbers were also at the lower end of the range of the WDFW estimates used in the model calibration. In the no fish passage scenario, the predicted maximum numbers of winter steelhead spawners were lower than any of the annual WDFW estimates used in the model calibration.

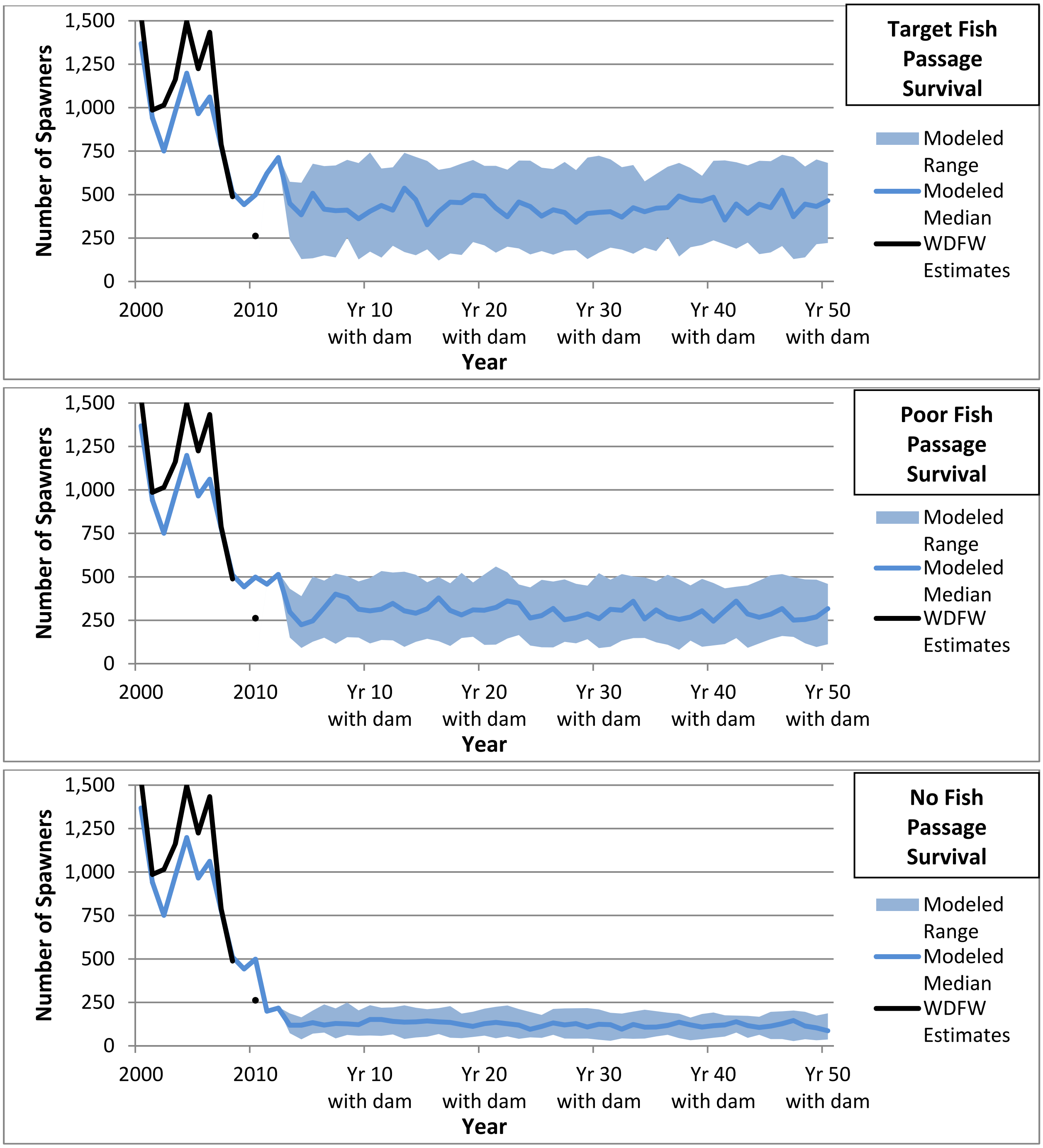


Figure F-24

Predicted Number of Winter Steelhead Spawners In Three Fish Passage Scenarios With An Optimized Multi-Purpose Dam

Note: The bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

4.4.3 Coho Salmon

With the construction and operation of an optimized multi-purpose dam that provides upstream and downstream fish passage, the number of coho salmon spawners is predicted to be low, but steady throughout the 50-year simulation (see Figure F-25). Assuming target survival rates past the dam are achieved, the predicted median number of spawners each year typically ranged between 350 and 600 fish. In the poor fish passage survival scenario, the predicted median numbers of coho salmon spawners each year were reduced further to 250 to 450 fish. In the no fish passage survival scenario, the predicted median numbers of coho salmon spawners each year typically ranged between 150 and 300 fish each year.

While the predicted median numbers could be interpreted to predict a smaller, but stable, coho salmon population compared to the spawner number estimates if existing conditions continued (see Figure F-19), the minimum number of spawners each year is an informative indicator of the potential for some low coho salmon returns with an optimized multi-purpose dam. Assuming target survival rates past the dam, the predicted minimum number of spawners each year typically ranged from 75 to 175 fish with fewer than 100 fish predicted in 11 out of 50 years. In the poor fish passage survival scenario, the minimum number of spawners predicted each year typically ranged from 50 to 100 fish with fewer than 100 fish predicted in 42 out of the 50 years analyzed. The numbers are even lower in the no fish passage survival scenario, as the minimum number of spawners predicted each year was fewer than 100 in 46 out of the 50 years, including 23 years with fewer than 50 spawners predicted.

Assuming target fish survival rates past the dam, the predicted maximum number of coho salmon spawners each year was in the middle of the range of the WDFW estimates used in the model calibration. In the poor fish passage survival and no fish passage survival scenarios, the predicted maximum numbers were at the lower end of the range of the WDFW estimates used in the model calibration.

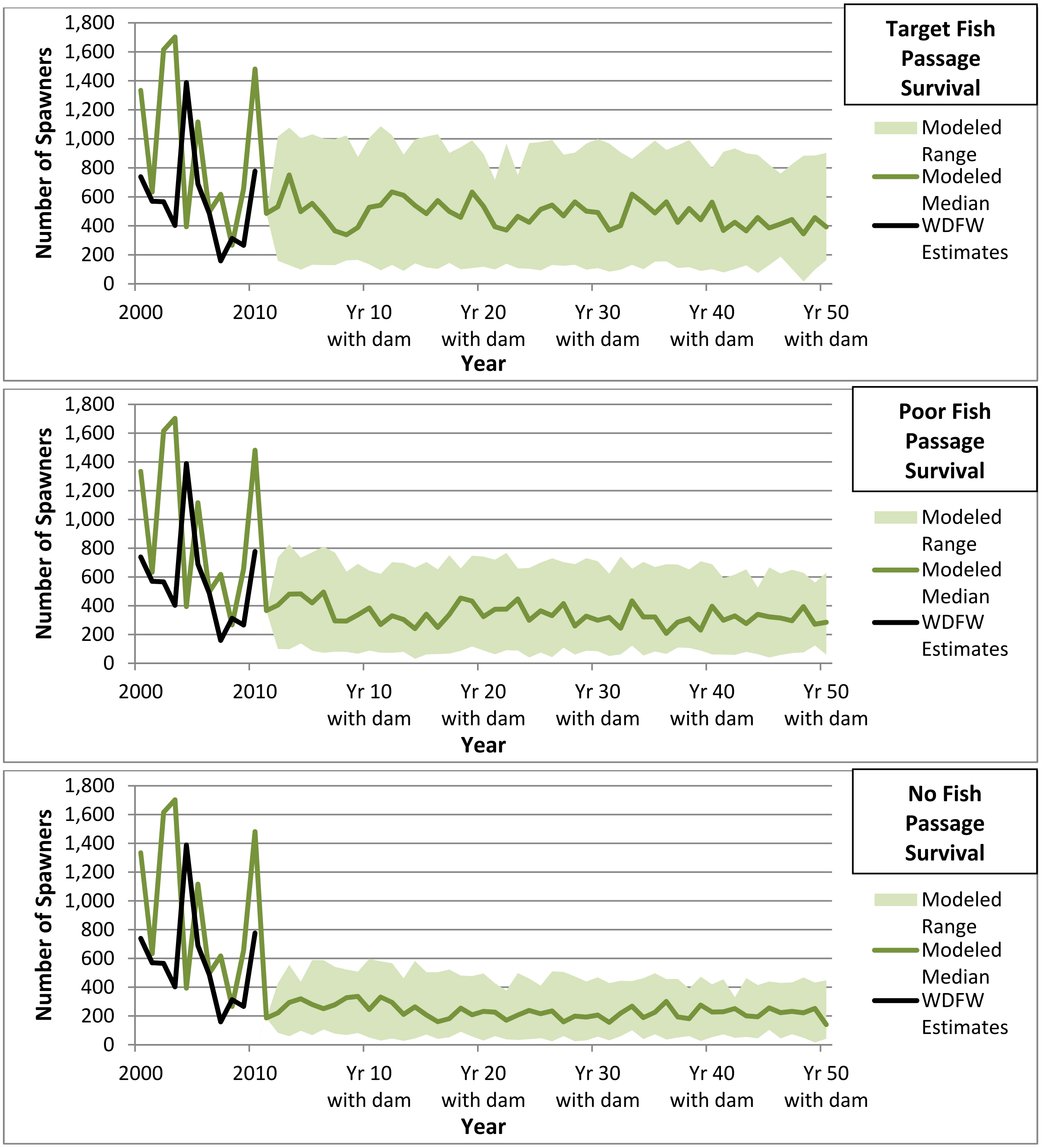


Figure F-25

Predicted Number of Coho Salmon Spawners In Three Fish Passage Scenarios With An Optimized Multi-Purpose Dam

Note: The bottom of the modeled range depicts the minimum number of spawners predicted each year and the top of the modeled range depicts the maximum.

4.5 Comparison of Salmonid Abundance in Each Dam Scenario Analyzed

In order to characterize the overall relative differences between the modeled effects of different dam scenarios on each salmonid species, the distribution of the predicted number of spawners throughout the 50-year simulation period was determined. For the purposes of presenting a comparison among all scenarios analyzed, the results are presented as the predicted minimum, first quartile, second quartile (median), third quartile, and maximum results[1]. These results are presented in a box-plot figure, as shown in Figure F-26.

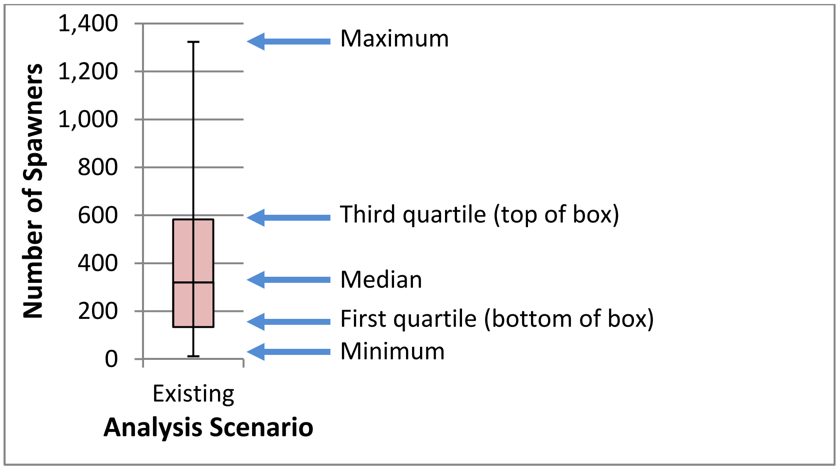


Figure F-26
Example of Box Plot Figure Used to Present 50 Years of Spawner Numbers Data

The results of the 50-year simulations for spring Chinook salmon, winter steelhead, and coho salmon are presented in Figure F-27 and Table F-35. Compared to the predicted number of spawners over the 50-year simulation period with the continuation of existing conditions, the optimized multi-purpose dam was predicted to produce an increase in spring Chinook salmon. All other dam scenarios for all three salmonid species were predicted to result in substantial reductions in the predicted number of spawners.

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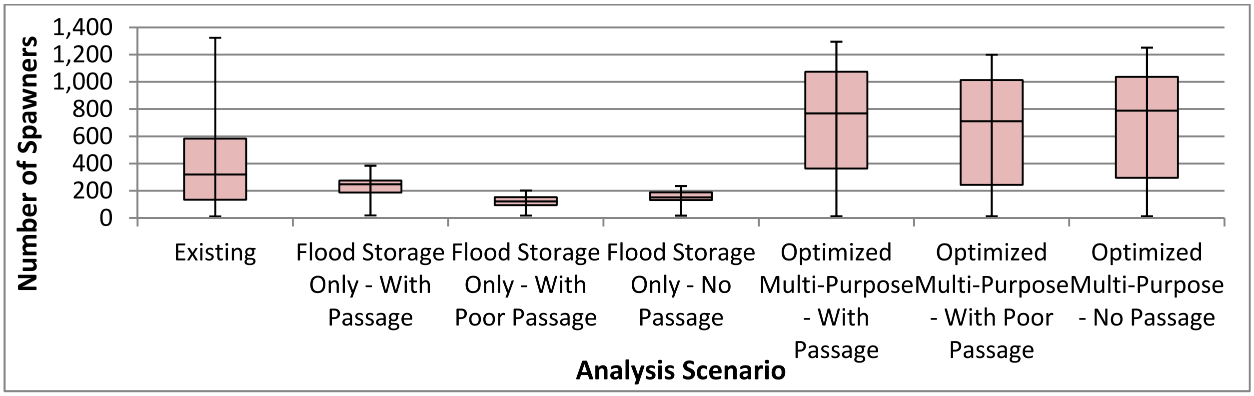
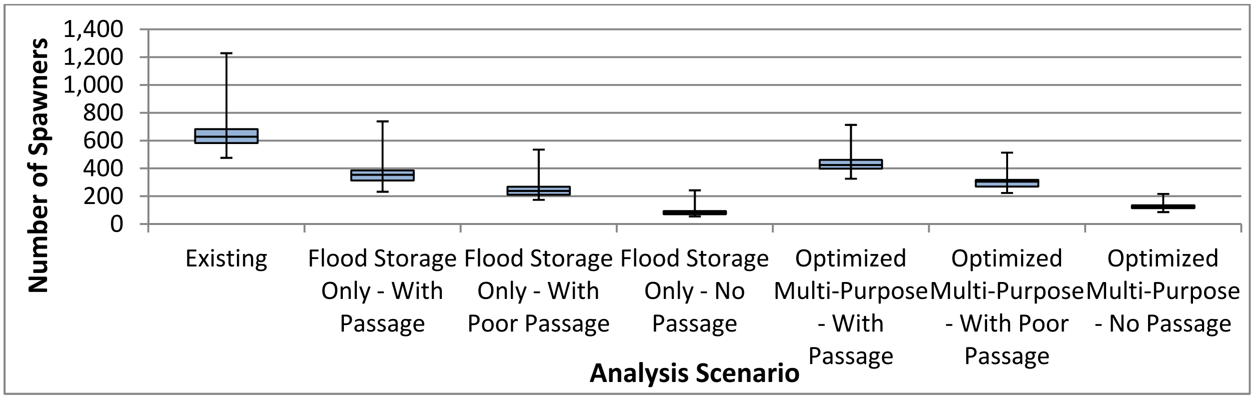
[1] The quartile results indicate the predicted number of spawners for which 25 percent of the predictions are lower (i.e., first quartile), 50 percent of the predictions are lower (i.e., second quartile or median), or 75 percent of the predictions are lower (i.e., third quartile).

Spring Chinook Salmon



Winter Steelhead



Coho Salmon

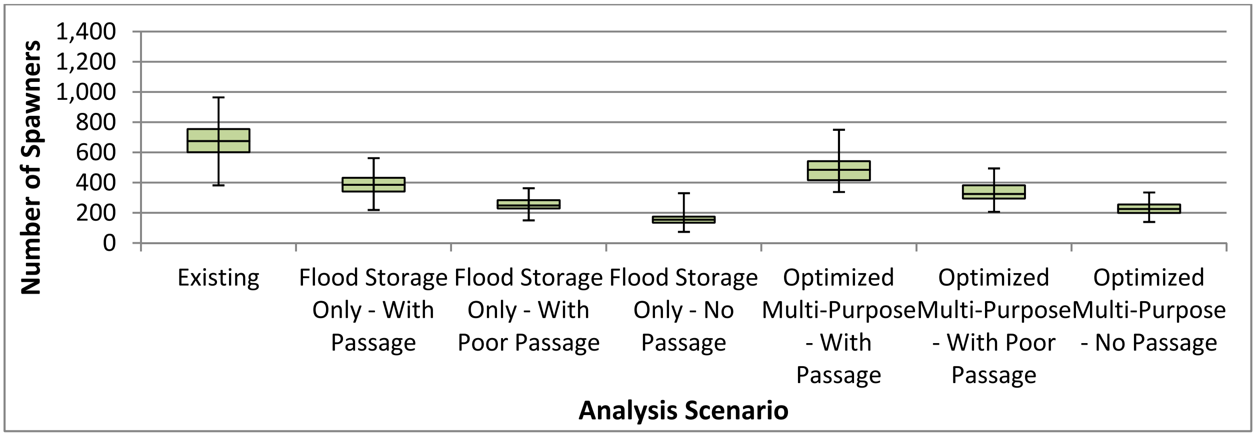


Figure F-27

Summary of the Number of Spawners Predicted in Each Analysis Scenario for Spring Chinook Salmon, Winter Steelhead, and Coho Salmon

Note: The box plots depict the minimum, first quartile, second quartile (median), third quartile, and maximum results as shown in Figure F-26.

Table F-35
Predicted Percent Change in the Median Number of Spawners Over 50-year simulation period Between the Existing Condition and Dam Scenarios

Dam Type	Fish Passage Analysis Scenario	Spring Chinook Salmon	Winter Steelhead	Coho Salmon
No Dam – Continuation of Existing Conditions		0%	0%	0%
Flood Storage Only Dam	With Target Fish Passage Survival	-22%	-43%	-43%
	With Poor Fish Passage Survival	-62%	-62%	-63%
	No Fish Passage Survival	-52%	-87%	-77%
Optimized Multi-Purpose Dam	With Target Fish Passage Survival	140%	-32%	-28%
	With Poor Fish Passage Survival	122%	-52%	-52%
	No Fish Passage Survival	146%	-81%	-67%

Among spring Chinook salmon, the predicted median number of spawners over the 50-year simulation period assuming the continuation of existing conditions was 320 fish. Assuming the target fish passage survival could be achieved in the flood storage only dam scenario, the predicted median number of spawners was 249, a 22 percent reduction compared to existing conditions. In the poor fish passage survival and the no fish passage survival scenarios of the flood storage only dam analysis, the predicted numbers of spawners were reduced to 122 and 152 fish, respectively. Compared to existing conditions, these are reductions of 62 percent and 52 percent, respectively. Among the optimized multi-purpose dam scenarios, the predicted median number of spring Chinook salmon spawners was 769 if target fish passage survival was achieved, 712 with poor fish passage survival, and 789 if no fish passage survival was attained. These are increases of 140 percent, 122 percent, and 146 percent relative to the number of spawners predicted with the continuation of existing conditions. In a preliminary analysis in which the water releases in a multi-purpose dam scenario were not optimized for fish[2], the predicted number of spring Chinook salmon spawners were 54 percent to 69 percent lower than existing conditions estimates.

Among winter steelhead, the predicted median number of spawners over the 50-year simulation period assuming the continuation of existing conditions was 628 fish. Assuming the target fish passage survival could be achieved in the flood storage only dam scenario, the

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[2] Water releases presented in EES Consulting (2011) were used in this preliminary analysis. The flows presented in EES Consulting (2011) were placeholder releases until more analyses were conducted, but can generally be considered to emphasize hydropower generation, more so than fish habitat.

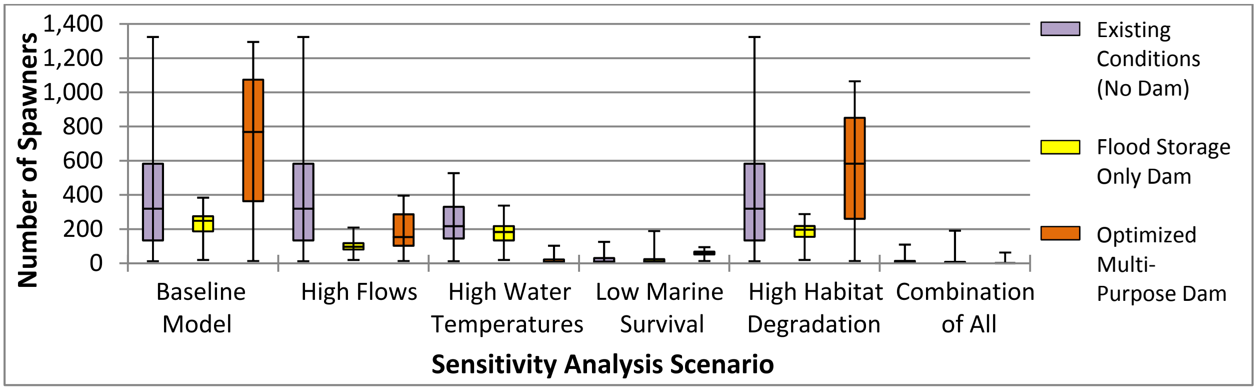
predicted median number of spawners was 355, a 43 percent reduction compared to existing conditions. In the poor fish passage survival and the no fish passage survival scenarios of the flood storage only dam analysis, the predicted numbers of winter steelhead spawners were reduced to 238 and 80 fish, respectively. Compared to existing conditions, these are reductions of 62 percent and 87 percent, respectively. Among the optimized multi-purpose dam scenarios, the predicted median number of winter steelhead spawners was 425 if target fish passage survival was achieved, 305 with poor fish passage survival, and 122 if no fish passage survival was attained. These are decreases of 32 percent, 52 percent, and 81 percent relative to the number of spawners predicted with the continuation of existing conditions.

Among coho salmon, the predicted median number of spawners over the 50-year simulation period assuming the continuation of existing conditions was 676 fish. Assuming the target fish passage survival could be achieved in the flood storage only dam scenario, the predicted median number of coho salmon spawners was 386, a 43 percent reduction compared to existing conditions. In the poor fish passage survival and the no fish passage survival scenarios of the flood storage only dam analysis, the predicted numbers of spawners were reduced to 250 and 155 fish, respectively. Compared to existing conditions, these are reductions of 63 percent and 77 percent, respectively. Among the optimized multi-purpose dam scenarios, the predicted median number of coho salmon spawners was 485 if target fish passage survival was achieved, 326 with poor fish passage survival, and 226 if no fish passage survival was attained. These are decreases of 28 percent, 52 percent, and 67 percent relative to the number of spawners predicted with the continuation of existing conditions.

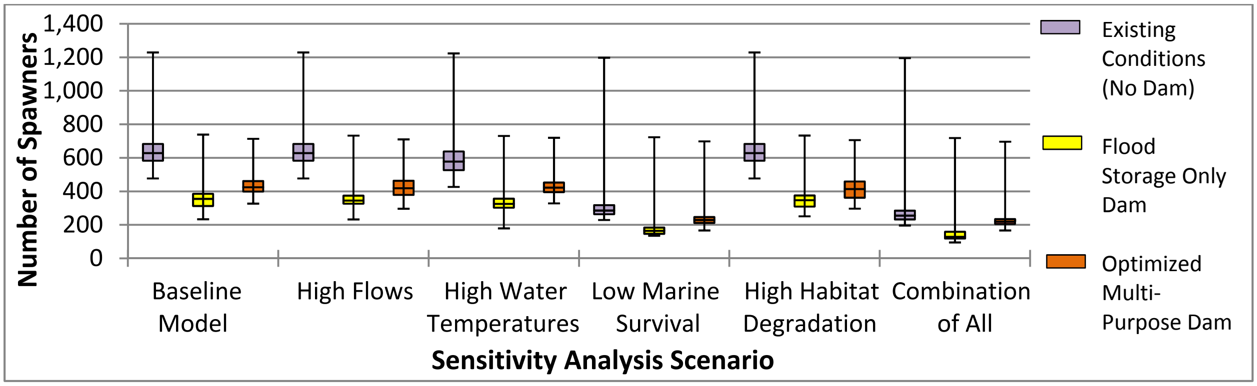
4.6 Sensitivity Analyses

The sensitivity analyses examined how changes in estimated future habitat conditions affected salmonid populations in each scenario. The sensitivity analyses predicted reductions in the numbers of spawners for each species in both dam scenarios (Figure F-28).

Spring Chinook Salmon



Winter Steelhead



Coho Salmon

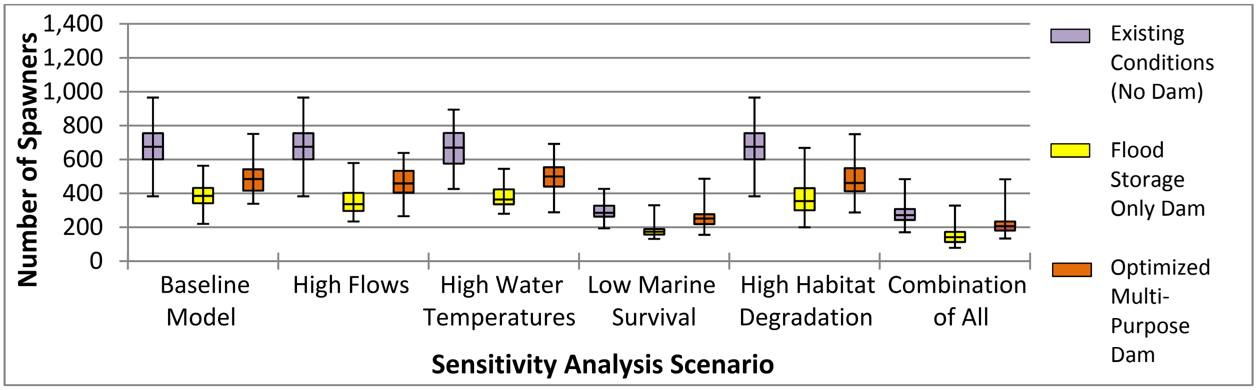


Figure F-28

Summary of the Number of Spawners Predicted in the Sensitivity Analyses for Spring Chinook Salmon, Winter Steelhead, and Coho Salmon

Note: The box plots depict the minimum, first quartile, second quartile (median), third quartile, and maximum results as shown in Figure F-26.

The predicted number of winter steelhead and coho salmon spawners in each sensitivity analysis was consistently highest with the continuation of existing conditions (i.e., no dam), followed by the optimized multi-purpose dam, and the flood storage only dam. A different pattern was evident in the spring Chinook salmon simulations. The spring Chinook salmon sensitivity analysis assuming low marine survival and the sensitivity analysis assuming high habitat degradation both predicted the highest number of spawners in the optimized multi-purpose dam scenario. However, the opposite was predicted in the sensitivity analysis assuming high water temperature and in the sensitivity analysis comining all altered parameters, as the lowest numbers of spring Chinook salmon spawners was predicted in the optimized multi-purpose dam scenario for both of these sensitivity analyses.

In the sensitivity analyses for all three salmonid species, the single parameter that resulted in the highest predicted reduction in the number of spawners was low marine survival. For spring Chinook salmon, the next largest reductions in the number of spawners were predicted assuming high flows or high water temperatures. For winter steelhead and coho salmon, only slight reductions were predicted compared to the baseline model in the other single parameter sensitivity analyses.

5 DISCUSSION

The fish population modeling analyses for all three salmonid species predicted substantial reductions in the predicted number of spawners in the flood storage only dam and optimized multi-purpose dam analyses compared to the continuation of existing conditions, except in the case of spring Chinook salmon with an optimized multi-purpose dam. These reductions ranged from 22 to 87 percent depending on dam and species analyzed. These reductions occurred regardless of the fish passage survival rate achieved, although the reductions were much greater if target fish passage survival rates could not be achieved. Despite the fact that fish passage designs are being continuously improved, there is an element of uncertainty regarding the success of any fish passage system.

None of the scenarios predicted extirpation of the salmonid populations analyzed. Winter steelhead and coho salmon are more dependent upon upper watershed habitats for spawning that spring Chinook salmon. In the scenarios assuming no fish passage survival past the dams, the predicted numbers of winter steelhead and coho salmon spawners were reduced by between 67 and 87 percent, which fits with the WDFW estimate that 91 percent of the spawning of both populations occurs upstream of the proposed dam site. These reductions appear to reflect that the loss of habitat is slightly offset by the fishes' affinity for straying.

The increase in the median predicted number of spring Chinook spawners with an optimized multi-purpose dam is likely due to the flow rates that maximize fish habitat spawning and rearing area, as well as the improved (lower) water temperatures downstream of such a facility. These changes in mainstem river conditions downstream of a dam would improve habitat conditions in the portion of the river where WDFW estimates 94 percent of the spring Chinook mainstem spawning occurs. The apparent contribution of the optimized flows to the spring Chinook salmon results was supported by the preliminary analysis of the multi-purpose dam without flows to maximize habitat, as the predicted number of spring Chinook spawners was reduced by more than 50 percent regardless of fish passage survival. Higher numbers of spawners with optimized flows were not predicted for winter steelhead and coho salmon spawners, likely because those species rely on upper watershed habitat above the proposed dam site, as documented in WDFW's estimate that 91 percent of both species spawn above the proposed dam site.

The sensitivity analysis of the changes in the predicted numbers of spawners if less favorable environmental conditions occur in the future (compared to the last 20 years on which the base model predictions were based), indicate that either a flood storage only dam or a multi-purpose dam would reduce the number of spawners compared to the predicted number of fish with the continuation of existing conditions. In this way, this analysis indicates that the resiliency of the salmonid populations to less favorable environmental conditions is reduced with either type of dam.

This analysis focused on the mainstem populations of three salmonid species. Either type of dam would also be expected to impact other fish in the mainstem and upper watershed study area, as well as fish populations using the tributaries off the mainstem Chehalis that may make use of the mainstem habitats for migration or rearing. For those fish species in the upper watershed, the types of anticipated alterations to habitat quantity and quality may be detrimentally impacted. For those fish species using tributaries off the mainstem Chehalis River and migrating through the lower mainstem, the augmented low flows provided in the optimized multi-purpose dam scenario may improve habitat quantity and quality. These potential impacts to other fish, as well as other aquatic organisms and wildlife species, should be evaluated in a comprehensive assessment of the environmental impacts of a dam on the upper mainstem of the Chehalis River.

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