APPENDIX A –

SHIRAZ MODEL METHODS

Prepared for:

Squaxin Island Tribe Natural Resources Department

Authored by:

Confluence Environmental Company

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1 INTRODUCTION

The habitat-based population simulation model SHIRAZ was applied as a tool to inform the 2015 Deschutes River Coho Salmon Recovery Plan. A SHIRAZ model version developed in 2008 (Anchor Environmental 2008) to support an earlier coho salmon analysis was updated for this analysis.

The methods information presented in this Appendix is derived primarily from the Anchor Environmental (2008) report. Limited updates were made to the peak flow and low flow inputs between 2008 and 2014. Also updated is text describing summer water temperature inputs and calibration results.

The basis of the SHIRAZ model is the Beverton-Holt stock recruitment model (Beverton and Holt 1957). The SHIRAZ model applies information on habitat features influencing the productivity and capacity of the river for producing coho to estimate the number of coho surviving each life stage in spatially distinct Assessment Reaches. The model allows the user to input watershed data on habitat conditions, coho population distributions, and the functional relationships between habitat and coho production. Model outputs are provided as the number of coho surviving each defined life stage in each Assessment Reach defined by the user. In this way, variations in the predicted number of coho provide insight on the effects of variations in model input (e.g., restored habitat).

This report describes the development of functional relationships between habitat conditions and coho production in the Deschutes River watershed, and the construction of a SHIRAZ model utilizing these function linkages to characterize coho salmon population dynamics. Functional relationships developed in Anchor Environmental (2008) were retained and applied in this updated analysis.

1.1 Project Area Overview

The Deschutes River watershed in Thurston County, Washington, encompasses approximately 166 square miles. The river originates on Cougar Mountain (3,870 feet) in the Snoqualmie National Forest and flows in a northwesterly directions for 57 miles. The river empties into Capitol Lake then drains into Budd Inlet in south Puget Sound (Figure 1). Historically, a natural barrier at the mouth of the river prevented anadromous salmonids from entering the river system. In 1951, the lower 2 miles of the river were impounded to create Capitol Lake in the City of Olympia. In 1954, a fish ladder was completed at the natural barrier (named Tumwater Falls) at the head of Capitol Lake. The fish ladder allowed anadromous salmonid populations to utilize the Deschutes River and its tributaries. The upper extent of anadromous salmonid distribution in the river is Deschutes Falls at river mile (RM) 41.

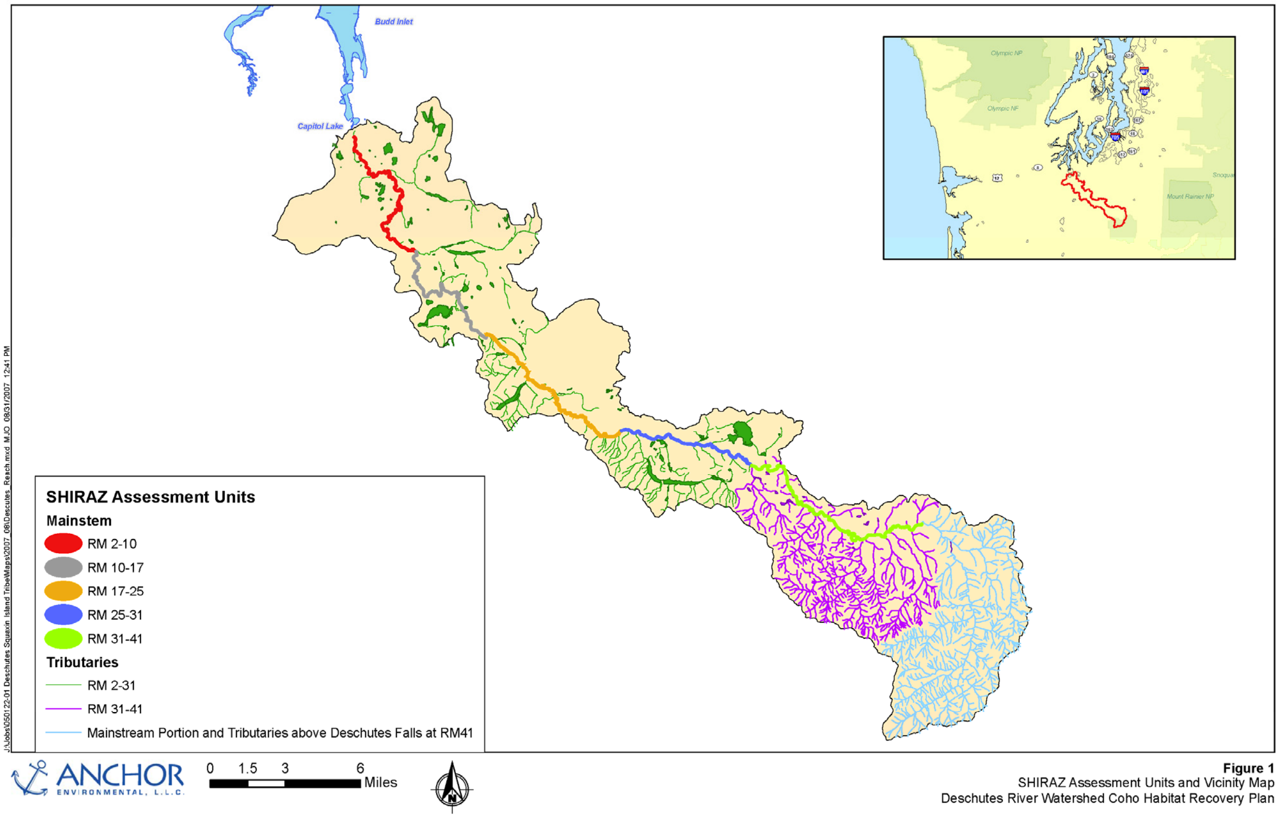


Figure 1
SHIRAZ Assessment Units and Vicinity Map
Deschutes River Watershed Coho Habitat Recovery Plan

Source of Figure: Anchor Environmental (2008)

Much of the upper watershed occurs in the transient snow zone between 1,100 and 3,600 feet elevation (Haring and Konovsky 1999). Transient snow zones are areas where rain-on-snow precipitation events are common. The lower 41 miles of drainage flow through a broad prairie-type valley floor. Much of the middle-upper and upper watershed is managed for timber harvest by the Weyerhaeuser Company. The middle portion of the watershed also supports open farmland interspersed with dense stands of mixed deciduous and coniferous growth (Haring and Konovsky 1999). The lower portion of the watershed is an urban growth management area where the river flows through the city of Olympia.

1.2 Coho Salmon Population Overview

Coho salmon are not native to the Deschutes River. Hatchery-raised coho from around Puget Sound (primarily Green River stock) were introduced to the river between the late 1940s and 1981 (WDF et al. 1993). Since 1981, there have been no coho releases into the Deschutes basin, although releases from nearby net pens are believed to provide low numbers of adult hatchery strays (WDF et al. 1993). Due to the absence of hatchery releases, the stock is sustained by natural production and strays.

In 2002, the Washington Department of Fish and Wildlife (WDFW) rated the Deschutes River coho stock as critical because of a severe short-term decline in adult wild return numbers between 1998 and 2001. Recent WDFW data indicate the continuation of low numbers of returns (WDFW 2007; Table 1). WDF et al. (1993) indicates that the natural escapement goal for the Deschutes River is 8,100 coho.

Table 1
Natural Origin Adult Coho Returns to the Deschutes River

Return Year	Number of Natural Origin Adult Coho Returns
1980	2,882
1981	3,843
1982	8,604
1983	4,640
1984	4,595
1985	5,934
1986	4,505
1987	10,395
1988	7,588
1989	974
1990	3,000
1991	1,981
1992	420
1993	639
1994	2,710
1995	582
1996	498
1997	1,083
1998	63
1999	45
2000	954
2001	55
2002	20
2003	2,306
2004	72
2005	135
2006	985
2007	156
2008	81
2009	1,793
2010	56
2011	98
2012	2,325
2013	38
2014	27

2 METHODS FOR SHIRAZ MODEL DEVELOPMENT

The methods information presented in this Appendix is derived primarily from the Anchor Environmental (2008) report. Limited updates were made to the peak flow and low flow inputs between 2008 and 2014. Also updated is text describing summer water temperature inputs and calibration results.

The SHIRAZ model characterizes coho salmon production by life stage for individual Assessment Reaches within the project area. In the Deschutes River watershed, seven Assessment Reaches were identified through consultation with the Squaxin Island Tribe based on coho utilization and location within the watershed, as described in Table 2.

Table 2
SHIRAZ Model Assessment Reaches

Assessment Reach	Description
Mainstem RM 2 to 10	This reach extends from the fish ladder at Tumwater Falls upstream to the confluence of Spurgeon Creek with the river. Spurgeon Creek is the largest creek in the lower river.
Tributaries RM 2 to 31	Tributaries below RM 31 are generally not utilized by coho as spawning areas, but provide rearing habitat.
Mainstem RM 10 to 17	Transition reach from lower to middle portion of project area.
Mainstem RM 17 to 25	Middle portion of project area.
Mainstem RM 25 to 31	Transition reach from middle to upper portion of project area.
Mainstem RM 31 to 41	Upper reach of project area and upper extent of anadromous fish distribution due to presence of Deschutes Falls at RM 41.
Tributaries RM 31 to 41	These tributaries provide the most utilized spawning areas in the watershed.

Parameters used in the SHIRAZ model had to meet two criteria: 1) there needed to be a documented link between the parameter condition and coho production; and 2) Deschutes River watershed data had to be available for the parameter. The documented link could be in peer-reviewed literature or unpublished “gray” literature. In considering data availability, no new data were collected for this investigation. The parameters that met these criteria were:

- Peak flows
- Low flows
- High water temperatures
- Fine sediments
- Large woody debris (LWD)

- Rearing area
- Spawning area

2.1 Model Inputs Describing Coho Life History and Watershed Distributions

The model was constructed using a simplified coho life history in which all coho completed the cycle in 3 years; this life history pattern is typical of most coho populations (Sandercock 1991). That is, adults return and deposit eggs in the fall of year *i*, alevins emerge and freshwater rearing occurs in year *i* + 1, smolts outmigrate to the ocean in year *i* + 2, and the adults return to begin the cycle again in the fall of year *i* + 3. This assumption of little to no variability in the duration of freshwater and marine residency is a convention used in virtually all coho life models. It facilitates the tracking of three isolated cycle lines for the population.

There is not an extensive amount of data to describe the spawning and rearing distributions of coho in the Deschutes River watershed. Models inputs for the spatial distributions of coho spawning and rearing in each of the assessment reaches were based on descriptive information in WDFW Salmon and Steelhead Stock Inventory maps (2002), Haring and Konovsky (1999), and Sullivan et al. (1988). For model simplification, it was assumed that there was no colonization of spawning reaches. That is, fish produced in a reach will return and spawn in the same reach. This was a reasonable assumption for investigating restoration effects on coho population size, particularly since the system is not considered habitat capacity limited.

2.2 Model Inputs to Describe Habitat Quantity

2.2.1 Rearing Area

A fundamental component of the Beverton-Holt (1957) model upon which the SHIRAZ model is built is the carrying capacity of the environment. Coho rearing area in the mainstem of the Deschutes River was calculated as the area within the vegetated width of the river as well as any adjacent wetlands. The delineation of this area was performed by Seto (2007). Rearing area within each mainstem Assessment Reach was calculated by dividing the mainstem into the reaches and using ArcGIS calculation tools for area. Rearing area within the tributaries was calculated based on the coho rearing distribution depicted in Haring and Konovsky (1999) and the WDFW Salmon and Steelhead Stock

Inventory maps (2002) and assuming a stream width of 16.4 feet. Rearing areas in each Assessment Reach are presented in Table 3.

Table 3
Rearing Area in Each Assessment Reach

Assessment Reach	Rearing Area (square feet)
Mainstem RM 2 to 10	2,844,082
Tributaries RM 2 to 31	3,507,320
Mainstem RM 10 to 17	2,177,817
Mainstem RM 17 to 25	2,737,875
Mainstem RM 25 to 31	2,128,586
Mainstem RM 31 to 41	3,361,505
Tributaries RM 31 to 41	3,468,797

2.2.2 Spawning Area

Spawning area was calculated by adjusting the rearing area estimates by the percentage of the Assessment Reach with suitable spawning gravel. Suitable spawning substrate size for coho salmon ranges from 0.5 to 6 inches with less than 20 percent of the substrate smaller than 0.25 inches (Hassler 1987). WDFW also uses 0.5 to 6 inches as optimal spawning substrate sizes for salmon (WDFW and Ecology 2004). The percentage of stream segments within each mainstem Assessment Reach with suitable spawning substrate was calculated using data from the Cramer (1997) reach analysis for the mainstem. The percentages of stream segments within the Tributary RM 2 to 31 and RM 31 to 41 reaches with suitable spawning substrate were calculated using descriptive information provided in Haring and Konovsky (1999) and data from the Squaxin Island Tribe (1991), respectively. Cramer (1997) provided pebble counts at multiple stream segments (range 43 to 87) within each of the Assessment Reaches defined for this study. For each mainstem Assessment Reach, the percentage of the stream segment with greater than 50 percent of the substrate between 0.9 and 5 inches and less than 20 percent of the substrate smaller than 0.3 inches (the closest size bin categories to target sizes) was calculated. In the Tributaries RM 31 to 41 Assessment Reach, data from nine stream segments in four different tributaries were used to calculate the percentage of the stream segments with suitable spawning substrate sizes. Table 4 presents the rearing area, percentage of Assessment Reach with suitable spawning substrate, and calculated suitable spawning area in each Assessment Reach.

Table 4
Spawning Area Calculation in Each Assessment Reach

Assessment Reach	Rearing Area (square feet)	Percentage of Reach with Suitable Spawning Substrate	Spawning Area (square feet)
Mainstem RM 2 to 10	2,844,082	87	2,522,121
Tributaries RM 2 to 31	3,507,320	50	3,507,205
Mainstem RM 10 to 17	2,177,817	78	2,177,830
Mainstem RM 17 to 25	2,737,875	86	2,737,887
Mainstem RM 25 to 31	2,128,586	68	2,128,595
Mainstem RM 31 to 41	3,361,505	65	3,361,515
Tributaries RM 31 to 41	3,468,797	100	3,469,004

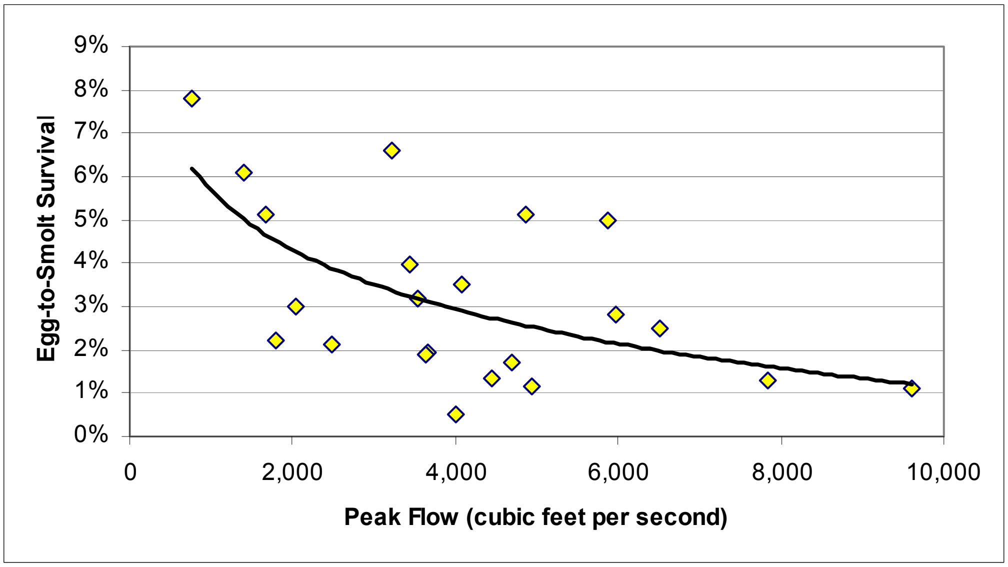
2.3 Model Inputs to Describe the Functional Quality of Habitat

This section describes the scientific rationale for including peak flows, low flows, high water temperatures, fine sediment loads, and LWD as factors affecting the functional quality of habitat in the Deschutes River watershed and, ultimately, coho production. This section also describes the identified functional relationship between the parameters and coho survival and the model inputs. A functional relationship used as a model input describes the changes in the proportion of coho surviving a selected life stage over a range of conditions for a parameter. Typically, the range varies from optimal (1.0) to suboptimal or even lethal (0.0). The proportion of coho surviving and the habitat condition linked to that proportion is user-defined. For the Deschutes River model, functional relationships were identified based on peer-reviewed and unpublished literature, as well as (in some cases) the interpretation of observational data from the watershed on habitat conditions and coho survival. Natural coho production data for the Deschutes River beginning with 1977 were available from WDFW. WDFW operates a smolt trap on the lower river and the adult fish ladder facility at Tumwater Falls (RM 2).

2.3.1 Peak Flows

As is typical of western Washington watersheds, the highest river flows in the Deschutes River occur during winter rain and early spring snowmelt events. Because coho spawn between November and January, their eggs incubate in the gravel during the period of highest flows. As a result, their eggs are vulnerable to scour during their incubation period. High rates of salmon egg and alevin mortality can occur due to scour or aggradation caused by high flows (McHenry et al. 1994).

The functional relationship between peak annual flow rates and coho egg-to-smolt survival was developed based on data from the U.S. Geological Survey (USGS) gage on the Deschutes River at Rainier (12079000). A regression between daily peak flows and the coho egg-to-smolt survival documented by WDFW between 1987 and 2005 explained 35 percent of the variability ($r^2 = 0.35$; Figure 2). The functional relationship developed followed approximately the same shape as the logarithmic regression (Figure 3).



Sources: WDFW egg-to-smolt survival data and USGS flow data at gage 12079000
Note: Line depicts logarithmic regression line describing relationship (r2 = 0.35)

Figure 2
Relationship between Peak Annual Flows and Coho Egg-to-Smolt Survival in the Deschutes River

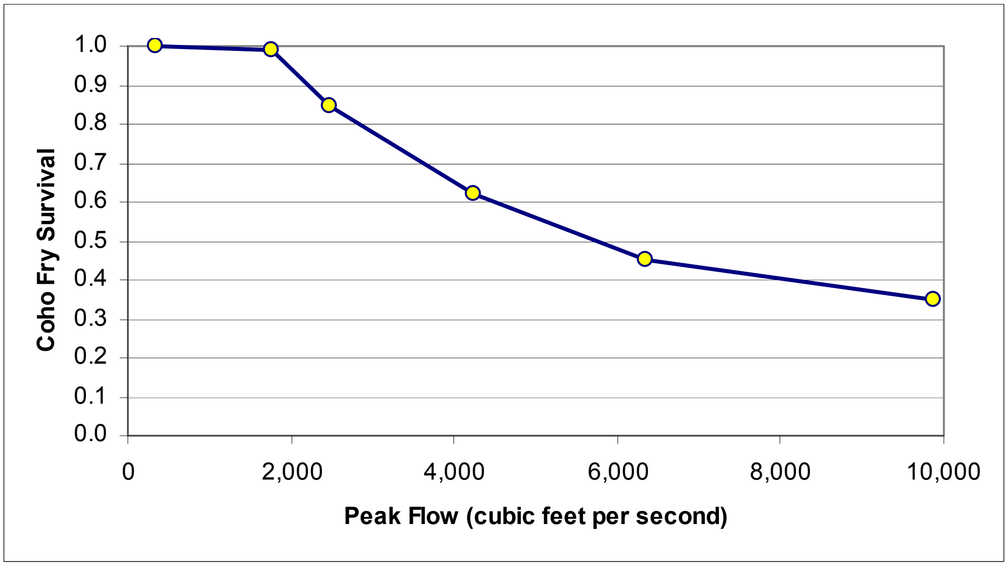


Figure 3
Functional Relationship Between Peak Annual Flow Rates and Coho Egg-to-Fry Survival

Peak flow data from the USGS gage on the Deschutes River at Rainier (12079000) are presented in Table 5. For years in which no data were available, the peak flow input for the model was adjusted to improve the calibration of the overall model to observed adult returns (i.e., reduce the difference between predicted returns and actual returns). For future years (2006 to 2050), the average of the years with data was used in the model. This average daily peak flow in a water year was 3,355 cubic feet per second (cfs).

Table 5
Peak Flows Between December and March at Tumwater Falls (RM 2) on the Deschutes River

Water Year	Peak Flow (cfs)
1979	3,670
1980	No data
1981	2,490
1982	4,440
1983	No data
1984	No data
1985	No data
1986	No data
1987	No data
1988	4,950
1989	1,800
1990	9,600
1991	5,980

1992	3,630
1993	1,660
1994	1,400
1995	4,690
1996	7,850
1997	6,510
1998	3,550
1999	5,880
2000	3,440
2001	766
2002	4,860
2003	4,000
2004	2,030
2005	3,220
2006	5,280
2007	5,050
2008	6,190
2009	6,500
2010	2,270
2011	3,440
2012	4,100
2013	4,620
2014	4,510

Note: In years listed as having "no data," USGS did not have a calculated peak flow available.

2.3.2 Low Flow Rate

In western Washington watersheds, the lowest flows of the year typically occur during mid- to late summer and early fall. Analyses of historic western Washington data from as far back as 1935 have shown a positive relationship between summer streamflow and the natural production of coho (Smoker 1955 and Mathews and Olson 1980). That is, higher summer streamflows during the oversummer rearing of coho in year *i* tend to result in higher numbers of adult coho in year *i* + 2. This effect on coho can be due to low flows limiting juvenile coho access to rearing areas, increased high water temperatures, and decreased dissolved oxygen levels. For adult coho, low flows can limit upstream migration and access to tributaries for spawning. In this way, low flows can limit spawning areas and concentrate redds in areas which may be more vulnerable to scour during high flow events during egg incubation.

The functional relationship between low flows and coho survival was developed based on the relationship between WDFW smolt data and low flow data from the USGS gage on the Deschutes River at Rainier (12079000). Statistical analysis identified a modest negative relationship ($r^2 = 0.07$) between the number of days between May 1 and October 31 with low flows below 33 cfs and the number of outmigrating smolts the following year. Available data were from 1979 to 2005. The functional relationship developed followed approximately the same shape as the logarithmic regression (Table 6 and Figure 4).

Table 6
Functional Relationship Between Low Flows and Coho Fry Survival

Number of Days in a Year with Low Flow Rates Below 33 cfs	Proportion of Coho Fry Survival
0	1.0
40	0.9
80	0.82
140	0.75

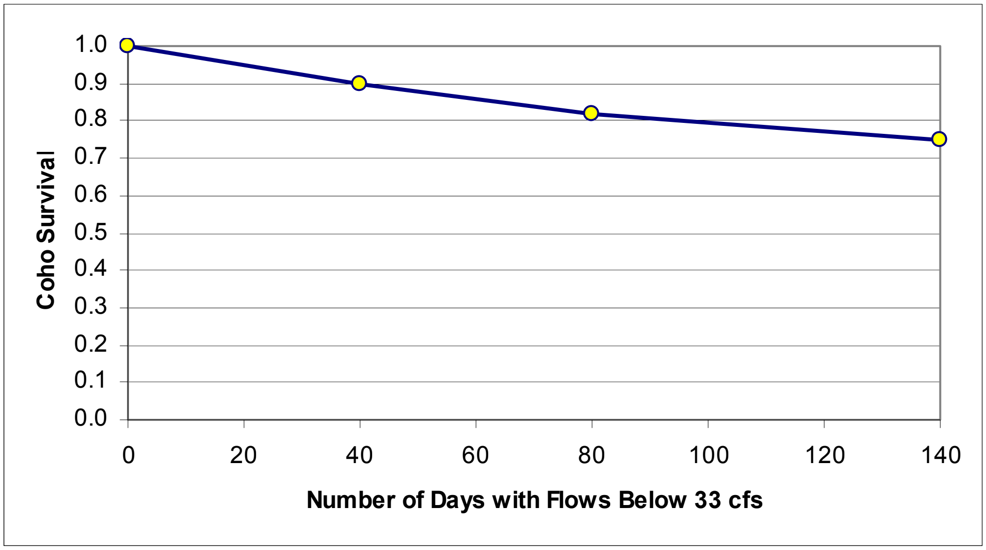


Figure 4
Functional Relationship Between Low Flows and Coho Fry Survival

Low flow data in the form of the number of days each year between May 1 and October 31 with flows below 33 cfs recorded at the USGS gage on the Deschutes River at Rainier (12079000) are presented in Table 7. For previous years in which no data were available, 1977 and 1978, the average number of days with flows below 33 cfs recorded during the first 6 years of the dataset was used. In this way, for years 1977 and 1978, a low flow value of 2 days was used in the model. For future years, the average of the years with data was used in the model. This average number of days with flows below 33 cfs was 64 days.

Table 7
Number of Days Between May 1 and October Each Year with Low Flows Below 33 cfs at the USGS Gage on the Deschutes River at Rainier (12079000)

Year	Number of Days Between May 1 and October 31 Each Year with Low Flows Below 33 cfs
1979	0
1980	9
1981	3
1982	2
1983	0
1984	0
1985	22
1986	54
1987	87
1988	28
1989	68
1990	2
1991	14
1992	77
1993	34
1994	63
1995	36
1996	37
1997	0
1998	50
1999	62
2000	29
2001	55
2002	80
2003	91
2004	28
2005	44
2006	98
2007	43
2008	41
2009	91
2010	0
2011	0
2012	34
2013	11
2014	50

2.3.3 High Water Temperatures

Water temperatures are a critical element of habitat quality for salmonids, because they impact salmonid survival, growth, and fitness. Richter and Kolmes (2004) identified 12 to 14 degrees Celsius as the preferred range for rearing juvenile salmon. Brett (1952) documented optimum growth between 12 and 14 degrees Celsius. Brett (1971) reported optimal physiological conditions at less than 15 degrees Celsius, and in another study, Brett (1952) documented marked avoidance of temperatures above 15 degrees Celsius. Frissell (1992) reported field studies findings that coho, cutthroat trout (*Oncorhynchus clarkii*), and yearling steelhead (*O. mykiss*) rearing densities decreased linearly as temperatures exceeded 17 degrees Celsius. Frissell (1992) also found that coho salmon juveniles were absent in waters that reached 21 to 23 degrees Celsius, except where thermal refugia were available.

The Water Quality Standards for Surface Waters of the State of Washington (Chapter 173-201 Washington Administrative Code [WAC]) set the upper temperature threshold in the Deschutes River watershed at 16 degrees Celsius for those areas upstream of the tributary to Offut Lake (RM 15). Downstream from the tributary to Offut Lake, the upper temperature threshold is 17.5 degrees Celsius.

The temperature threshold for analysis in the Deschutes River was defined as 16 degrees Celsius. Data from a temperature gage operated by Weyerhaeuser at 1000 Road (RM 37) were used for the analysis because this gage provides the most complete dataset over the period of analysis.

The functional relationship between summer daily maximum water temperatures and coho survival was developed based on the relationship between WDFW smolt data and the 1000 Road water temperature data. A long-term dataset of water temperatures at 1000 Road between May 1 and September 30 was available. This 153 day period was the basis of the statistical analysis and subsequent functional relationship development. Statistical analysis identified a negative relationship between the number of days each year with maximum water temperatures at 1000 Road exceeding 16 degrees Celsius and egg-to-smolt survival among smolts outmigrating the following year ($r^2 = 0.10$). Available data were from 1981 to 2004, and the number of days with maximum water temperatures at 1000 Road exceeding 16 degrees Celsius ranged from 32 to 94. The regression slope describing this relationship was used to describe the functional relationship between maximum water temperatures and coho fry survival for years with between 30 and 153 days with maximum water temperatures greater than 16 degrees Celsius (Table 8 and Figure 5). Since the regression analysis did not have data available for fewer days with maximum water temperatures exceeding 16 degrees Celsius, best professional judgment was applied to describe the diminished coho fry survival expected in such years.

Table 8
Functional Relationship Between Summer Water Temperatures and Coho Fry Survival

Number of Days in a Year with Daily Maximum Temperatures Greater Than 16 Degrees Celsius	Proportion of Coho Fry Survival
0	1.0
30	0.9
153	0.11

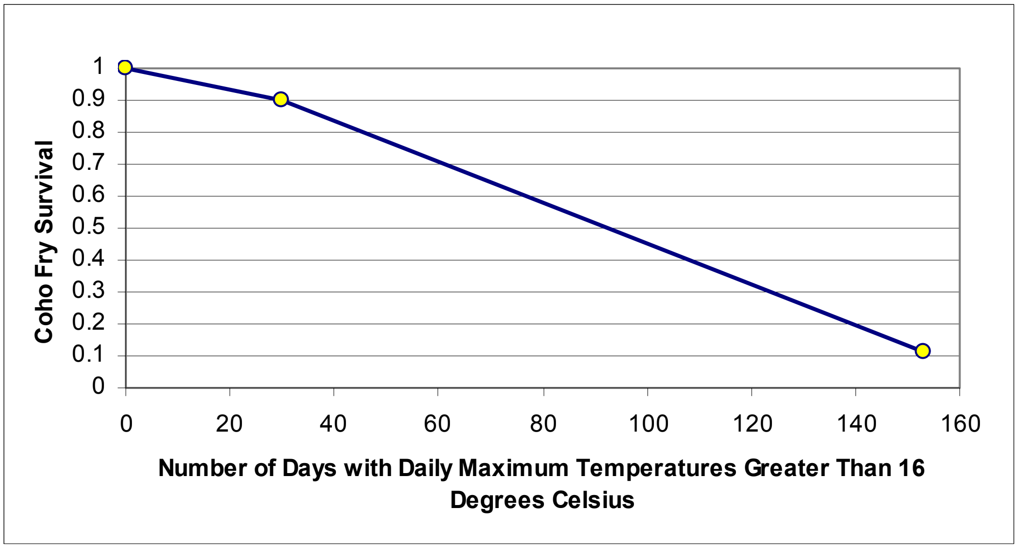


Figure 5
Functional Relationship Between High Water Temperatures and Coho Fry Survival

Summer water temperatures from 1000 Road were used in the analysis and were defined on an annual basis. The number of days exceeding 16 degrees Celsius during each year with available data is presented in Table 9. For years in which no data were available, the average of the years with data was used in the model. This average was 57 days per year.

Table 9
Number of Days that Daily Maximum Water Temperatures at 1000 Road Exceeded 16 Degrees Celsius

Year	Number of Days	Year	Number of Days	Year	Number of Days
1980	No data	1989	58	1998	78
1981	40	1990	56	1999	39
1982	No data	1991	56	2000	32
1983	52	1992	92	2001	40
1984	73	1993	45	2002	70
1985	72	1994	78	2003	80
1986	85	1995	58	2004	79
1987	72	1996	68	2005 – 2014	No data
1988	59	1997	94		

Note: In years listed as having "no data," an incomplete record of summer water temperatures was available.

2.3.4 Fine Sediments

For the purposes of this analysis, fine sediments were defined as sediment particles less than 0.85 millimeter (mm) in diameter. Field and laboratory studies have documented that higher percentages of fine sediments reduce salmon egg survival (Chapman 1988). McNeil and Ahnell (1964) found that fine sediments of less than 0.85 mm had the highest impact on salmonid spawning success. Several authors have documented that salmon egg survival decreases markedly when more than 10 percent fine sediment is present in redds (Koski 1966; Cedarholm et al. 1981; Tappel and Bjornn 1983). Other studies or protocols use slightly higher fine sediment percentages (e.g., Timber Fish and Wildlife Watershed Analysis Rating System uses 12 percent fine sediment as the threshold for decreased survival; McHenry et al. [1994] identified 13 percent fine sediment as the threshold).

Based on information on decreased survival with increasing percentages of fine sediments, a functional relationship was defined. The functional relationship describes the trend in the proportion of egg-to-fry survival based on percentage of fine sediments present (Table 10 and Figure 6).

Table 10
Functional Relationship Between the Percentage of Fine Sediments (Less than 0.85 mm in Diameter) in Substrate and Coho Egg Survival

Percent Fines in Substrate	Proportion of Coho Egg Survival
0	1.0
10	1.0
11	0.9
12	0.8
17	0.5
20	0.2
50	0.01
100	0.01

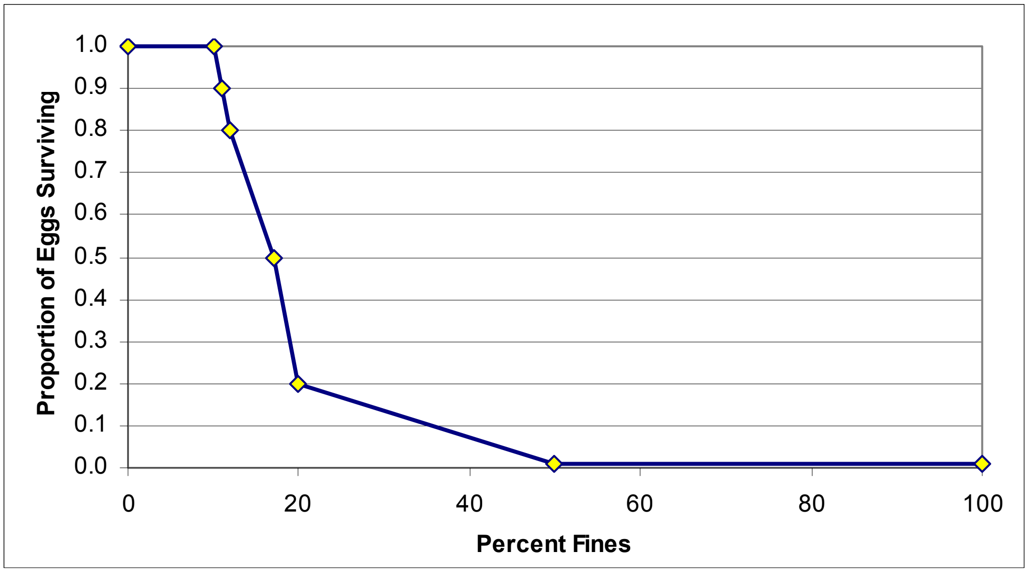


Figure 6
Functional Relationship Between the Percentage of Fine Sediments (Less than 0.85 mm in Diameter) in Substrate and Coho Egg Survival

The information sources for fine sediment data in the Deschutes River Assessment Reaches were fine sediment data for the mainstem river collected by Konovsky and Puhn (2005) and tributary data collected by Schuett-Hames and Flores (1994) as reported in Haring and Konovsky (1999). The dataset produced by Konovsky and Puhn (2005) included measurements of the percentage of fine sediments for one study site within each of the mainstem Assessment Reaches defined for this analysis. The fine sediment percentage in the Tributaries RM 2 to 31 Assessment Reach was an average of the Konovsky and Puhn (2005) data in the five mainstem Assessment Reaches. The fine sediment percentage in the Tributaries RM 31 to 41 Assessment Reach was the average of data from five tributaries in the Schuett-Hames and Flores (1994) study. The fine sediment data input to the model are presented in Table 11.

Table 11
Percentage of Fine Sediment in Each Assessment Reach

Assessment Reach	Percentage of Fine Sediment
Mainstem RM 2 to 10	22.0
Tributaries RM 2 to 31	19.7
Mainstem RM 10 to 17	19.5
Mainstem RM 17 to 25	20.2
Mainstem RM 25 to 31	17.0
Mainstem RM 31 to 41	17.3
Tributaries RM 31 to 41	14.0

2.3.5 Large Woody Debris (LWD)

LWD is defined as a log that is at least 7 feet long with a diameter of at least 4 inches . LWD provides habitat structure that juvenile coho use and is an important factor in pool formation (Bisson et al. 1987). Pools help retain organic matter and detritus and increase the amount of slow water habitat available (Sedell et al. 1988). LWD is used as an indicator of pool density, but is considered less subjective than available datasets that provided some estimation of pool abundance. LWD both within and outside the low flow channel may play a crucial role in helping fish survive winter high flow conditions (Reeves et al. 1991). LWD, including rootwads, can provide slow water areas during periods of high flow. Shirvell (1990) reported that 99 percent of all coho fry occupied positions immediately downstream of rootwads during periods of low, average, and high flows.

The use of LWD rather than pool data in the model was based on the fact that the available LWD information appeared to be more consistent and complete than the datasets on pools. Both parameters were not utilized in the model because they are typically highly correlated.

The functional relationship between LWD quantities and coho production was developed based on LWD quantity data presented in Fox and Bolton (2007) for three sizes of river and stream systems throughout western Washington (Table 12).

Table 12
Percentile Distribution of the Quantity of LWD per 328 Feet Stream Length for the Western Washington Region

Bankfull Width	Median	25th Percentile	75th Percentile
Less than 20 feet	29	26	38
20 to 98 feet	52	29	63
Greater than 98 to 328 feet	106	57	208

Source: Fox and Bolton (2007)

In this analysis, the central 50 percent of these data (i.e., as bounded by the 25th and 75th percentiles) was established as a reasonable target for habitat restoration in the Deschutes River. The intermediate bankfull width category (20 to 98 feet) describes the mainstem Assessment Reaches. The smallest bankfull width category (less than 20 feet) describes the tributary Assessment Reaches. The functional relationship was based on the percentage of each Assessment Reach that contains LWD quantities per 328 feet at or above the 25th percentile. For the mainstem, the minimum LWD requirement to count as favorable for coho was 29 or more pieces per 328 feet stream length. In tributaries, the minimum LWD requirement was 26 pieces per 328 feet stream length.

The literature describing the importance of LWD for salmon does not provide clear documentation of the survival or productivity impacts that result from little or no LWD availability in river systems. The functional relationship was developed based on best professional judgment of the role of LWD in the survival of fry to the over-wintering life stage (Table 13 and Figure 7).

Table 13
Functional Relationship Between LWD Quantities and Coho Fry Survival

Percent of Reach with Good or Fair LWD Conditions	Proportion of Coho Fry to Over-winter Survival
100	1.0
80	1.0
50	0.9
25	0.8
10	0.7
0	0.6

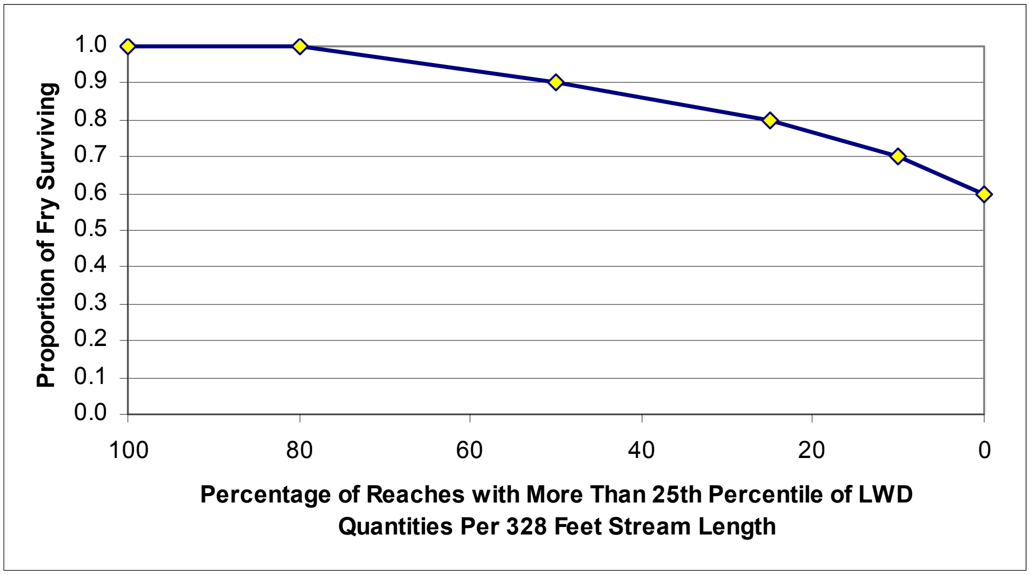


Figure 7
Functional Relationship Between LWD Quantities and Coho Fry Survival

Data on the quantities and distribution of LWD in the Deschutes River Assessment Reaches were obtained from a mainstem reach scale survey conducted by Cramer (1997) and tributary data collected by the Squaxin Island Tribe (1991). Cramer (1997) provided LWD counts at multiple stream segments (range 43 to 87) within each of the Assessment Reaches defined for this study. For each mainstem Assessment Reach, the percentage of the stream segments with LWD quantities per 328 feet in excess of the 25th percentile were calculated. The percentage of the streams in the Tributaries RM 2 to 31 Assessment Reach with LWD quantities per 328 feet in excess of the 25th percentile was calculated as the average of the mainstem Assessment Reach results. In the Tributaries RM 31 to 41 Assessment Reach, data from nine stream segments in four different tributaries was used to calculate the percentage of the stream segments with LWD quantities per 328 feet in excess of the 25th percentile. The LWD data input to the model are presented in Table 14.

Table 14
Percentage of River Length in Each Assessment Reach Meeting Established LWD Restoration Target

Assessment Reach	Percentage of River Length Meeting Established LWD Restoration Target[a]
Mainstem RM 2 to 10	2
Tributaries RM 2 to 31	1
Mainstem RM 10 to 17	0
Mainstem RM 17 to 25	0
Mainstem RM 25 to 31	2
Mainstem RM 31 to 41	0
Tributaries RM 31 to 41	60

Note: LWD restoration target based on 25th percentile of LWD quantity data for river size presented in Fox and Bolton (2007) and shown in Table 12.

2.4 Habitat Parameters Considered But Not Used in Model

A myriad of ecological parameters could potentially be used to describe the functional quality of the habitat for coho. The lack of a clear, defensible link between a parameter and coho production and/or the absence of an adequate dataset excludes other parameters from being included in this version of the model. Three parameters given some consideration but ultimately not included in the model were off-channel rearing habitat availability, pool availability, and total nitrogen levels. The importance of off-channel rearing habitat to the life cycle of coho has been well documented, but the parameter was not explicitly included in the model because of a lack of data on off-channel habitat availability in the watershed. Instead, the estimation of rearing habitat included the area contained in adjacent wetlands in order to generally describe off-channel habitat availability. An indicator of pool availability was not included because it is correlated to LWD, which is included in the model, and the estimation of pool availability in available datasets was considered to be a more subjective measure than the available LWD counts. Insufficient data on nitrogen levels in the watershed to support inclusion in the model prevented further consideration of this parameter.

2.5 Model Calibration

Model calibration is the process of iteratively refining model inputs in an effort to minimize the difference between predicted and actual outcomes. For this model, the WDFW coho production data (WDFW unpubl. data) provides an excellent long-term dataset comprised of empirical observations. Model predictions were refined by adjusting the peak flow entries in those years for which no data were available (1979 and 1982 through 1986).

3 MODEL CALIBRATION TO EMPIRICAL DATA

The model was calibrated to the number of natural origin coho salmon returning as adults between 1980 and 2006 (WDFW unpubl. data). The resulting model accurately estimated the number of fish returning in a given year and the general trend of returns over the period of comparison (Figure 8). However, the recent rebound in natural origin coho production is underestimated by the model, so baseline numbers used in model scenarios to predict coho production responses to improvements in freshwater survival through habitat restoration may underestimate actual numbers but still accurately predict population trends. Overall, the results suggest a high degree of confidence in the model's ability to characterize subsequent changes to the size of the Deschutes River coho population due to changes in the habitat parameters and marine survival conditions.

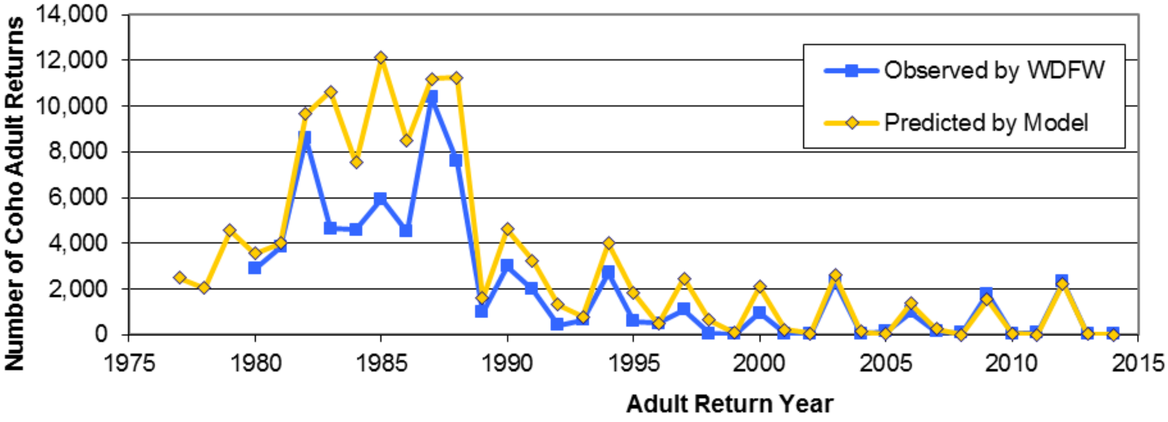


Figure 8
Comparison of Predicted and Actual Numbers of Natural Origin Adult Coho Salmon Returning

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