Effects of Flood Retention Alternatives and Climate Change on Aquatic Species

August 29, 2014

Report Prepared by

The Aquatic Species Enhancement Plan of the Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species

Prepared for

Chehalis Basin Work Group

TABLE OF CONTENTS

Executive Summary ES-1
Flood Reduction Alternatives ES-3
Alternatives Modeled ES-3
Results: Effects on Salmon ES-5
Results: Effects on In-channel Habitat for Other Fish and Non-fish Species ES-8
Results: Effects on Off-channel Habitat for Other Fish and Non-fish Species ES-9
Climate Change ES-9
Alternatives Modeled ES-9
Results: Effects on Salmon ES-10
Results: Effects on Other Fish and Non-fish Species ES-11
Combinations of Alternatives ES-12
Habitat Enhancement and Water Retention Alternatives ES-12
Water Retention and Climate Alternatives ES-13
Habitat Enhancement, Water Retention, and Climate Alternatives ES-16
Data Gaps and Scientific Uncertainty ES-17
Key Findings ES-18
1 Introduction 1
1.1 Introduction 1
1.2 Purpose 1
1.3 Scope 1
1.4 Implementation 2
1.5 Overview of the Chehalis Watershed 2
1.6 Selection of Key Species 4
1.7 Effects of Flood Hazard Reduction Structures on River Ecosystems 8
1.8 Recent Trends in Abundance of Chehalis Basin Salmonids 10
2 Analytical Framework 12
2.1 Introduction 12
2.2 Modeling Biological Effects 14
3 Description of Flood Reduction Alternatives, Dam Operations, and Fish Passage 16
3.1 Introduction 16
3.1.1 Summary of Proposed Dam Alternative Structures 16
3.1.2 Summary of Proposed Dam Operations 17
3.2 Methods for Evaluating Fish Passage 19
3.2.1 Flood Reduction Only Dam Alternative 19
3.2.2 Multi-purpose Dam Alternative 20
3.3 Fish Passage Considerations for Operation of Flood Retention Only Dam Alternative 20
3.3.1 Assessment of Annual Fish Passage 20
3.3.2 Assessment of Fish Passage by Species 20
3.4 Fish Passage Considerations for Operation of Multi-purpose Dam Alternative 25
3.5 Summary 27
4 Analysis of Flood Retention Alternatives on Aquatic Resources 29
4.1 Introduction 29
4.2 Water Retention Alternatives Modeled 29
4.2.1 Dam and Reservoir Footprint 30
4.2.2 Downstream from the Dam 30

4.3 Physical Processes Modeled and Preliminary Results of Juvenile Salmon Movement Studies 30
4.3.1 Chehalis Hydrology: Representative Years and Probabilities 30
4.4 Methods: Analyzing Salmon Species 36
4.5 Results: Salmon Species 37
4.5.1 Ecosystem Diagnosis & Treatment Model 37
4.5.2 SHIRAZ Model 44
4.6 Methods: Analyzing Other Fish and Non-fish Species 51
4.6.1 In-channel Habitat 52
4.6.2 Off-channel Habitat 54
4.7 Results: Other Fish and Non-fish Species 55
4.7.1 In-channel Habitat 55
4.7.2 Off-channel Habitat 61
4.8 Alternatives for Protecting Interstate 5 68
4.8.1 Methods 68
4.8.2 Results 68
4.9 Small Flood Protection Projects 68
4.9.1 Methods 68
4.9.2 Results 70
4.10 Discussion of Results 72
4.10.1 Effects on Salmon Species 72
4.10.2 Effects on Other Fish and Non-fish: In-channel Habitat 74
4.10.3 Effects on Other Fish and Non-fish: Off-channel Habitat 77
5 Analysis of Climate Change 80
5.1 Introduction 80
5.2 Estimating Climate Change 80
5.2.1 Projected Changes in Water Temperature Based on Air Temperature Change Projections 80
5.2.2 Stream Flows 82
5.2.3 Sea Level Rise 87
5.2.4 Summary of Projected Changes to the Chehalis Basin 89
5.3 Methods 89
5.4 Discussion of Results 94
5.4.1 Ecosystem DiagnosIs & Treatment 94
5.4.2 SHIRAZ 99
5.4.3 PHABSIM and HSI Analyses 100
5.4.4 Correlative Analysis 102
5.4.5 Potential Effects of Sea Level Rise 103
5.5 Discussion of Results 103
5.5.1 Effects of Climate Change on Salmon 103
5.5.2 Effects of Climate Change on Other Fish and Non-fish Species 103
6 Combinations of Alternatives 104
6.1 Habitat Enhancement and Water Retention Alternatives 104
6.2 Water Retention and Climate Alternatives 110
6.2.1 Results of Analysis on Salmon Using EDT 110
6.2.2 Results of Analysis on Salmon Using SHIRAZ 114
6.2.3 Results of Analysis on Other Fish and Non-Fish Species Using PHABSIM and HSI Analyses 115
6.3 Habitat Enhancement, Water Retention, and Climate Alternatives 116
7 Data Gaps and Scientific Uncertainty 118
7.1 Introduction 118
7.2 Water Retention Alternatives 118

7.3 Climate Change 118
7.4 Scientific Uncertainty 119
8 References 120

LIST OF TABLES

Table ES-1 Key Species Analyzed in the Aquatic Species Enhancement Plan ES-2
Table ES-2 Estimated Changes to Median Number of Mainstem Chehalis Salmon with Climate Change ES-15
Table 1.1 Key Species Analyzed in the Aquatic Species Enhancement Plan 6
Table 1.2 List of Non-native Species Evaluated in the Aquatic Species Enhancement Plan 8
Table 3.1 Total Duration Where Limited Fish Passage Occurs by Water Year, Water Years 1989 to 2012 21
(Without Extra Holding Time for Debris Management) 21
Table 3.2 Total Duration Where Limited Fish Passage Occurs by Water Year, Water Years 1989 to 2012 (With Extra Holding Time for Debris Management) 22
Table 3.3 Mean Monthly Duration of Limited Fish Passage, Water Years 1989 to 2012 23
(Without Extra Holding Time for Debris Management) 23
Table 3.4 Mean Monthly Duration of Limited Fish Passage, Water Years 1989 to 2012 (With Extra Holding Time for Debris Management) 23
Table 3.5 Annual Stage Duration Anticipated for Multi-purpose Flood Retention Dam Alternative Water Years 1989 to 2012 26
Table 4.1 Water Year Category Exceedance and Probability 31
Table 4.2 Representative Water Years 32
Table 4.3 Summary of Environmental Changes Assumed in the Water Retention Alternatives 37
Table 4.4 Changes in Abundance for Lower Chehalis River Salmonid Sub-populations Resulting from Water Retention Alternatives 40
Table 4.5 Changes in Abundance for Middle Chehalis River Salmonid Sub-populations Resulting from Water Retention Alternatives 41
Table 4.6 Changes in Abundance for the Upper Chehalis River Sub-populations Resulting from Water Retention Alternatives 44
Table 4.7 Hydraulic Habitat (WUA) Weighted for Seasonal Changes in Habitat and the Percent Change from Baseline Compared to Multi-purpose Dam Alternative Flow Release 59
Table 4.8 List of Small Flood Retention Projects Evaluated for Their Potential Effect on Aquatic Species 69
Table 4.9 List of Small Flood Retention Projects Evaluated for Their Potential Effect on Aquatic Species 70
Table 5.1 Water Temperature Changes to Be Included in the Climate Change Sensitivity Analysis Based on A1B Emissions Scenario 82
Table 5.2 Percent Change in Stream Flow to Be Included in the Climate Change Sensitivity Analysis Based on A1B Emissions Scenario 86
Table 5.3 Recommended Peak Flow and Low Flow Changes Included in Sensitivity Analysis Based on A1B Emissions Scenario 86
Table 5.4 Summary of Changes Related to Alternative Future Conditions Modeled in EDT 92
Table 5.5 Assumed Changes in Water Temperature in the Chehalis Based Under the Alternative Futures Scenarios 93
Table 5.6 Hydraulic Habitat (WUA) Response to Projected Decreases in Summer Stream Flow by Climate Change from Current (Baseline) Conditions for 2080 101
Table 6.1 Description of Combination Scenarios Analyzed for Chehalis Basin Salmonids 105
Table 6.2 Estimated Changes to Median Number of Mainstem Chehalis Salmon with Climate Change 114

Table 6.3 Percent Change in Hydraulic Habitat (WUA) Related to Decreases in Summer Stream Flow of -16.8% in July, -26.0% in August, and -18.4% in September from Climate Change and Proposed MPD Operations Relative to Current (Baseline) Conditions 116

LIST OF FIGURES

Figure ES-1 Species-level Changes in Salmonid Habitat Potential in the Chehalis Basin Resulting from Water Retention Alternatives Relative to Current Habitat Potential........ES-6

Figure ES-2 Estimated Number of Coho Salmon Spawners with Flood Reduction Only Dam ES-7

Figure ES-3 Species-level Effects of Alternative Climate Conditions on Chehalis Basin Salmonids ES-11

Figure ES-4 Proportional Changes in Chehalis Basin Salmonids from Current Abundance Due to Riparian Enhancements, Culvert Removal and Flood Reduction Alternatives........ES-13

Figure ES-5 Effect of Flood Reduction Alternatives on Chehalis Basin Salmon Under Alternative Future Conditions ES-14

Figure ES-6 Proportional Changes in Chehalis Basin Salmonids from Current Abundance Due to Climate Change, Habitat Enhancement, and Flood Reduction Alternatives........ES-17

Figure 1.1 The Chehalis River Basin........3

Figure 1.2 Recent Spawning Escapement and Total Run Size for Chehalis River Coho Salmon, Fall-run Chinook Salmon, Spring-run Chinook Salmon, and Winter-run Steelhead 11

Figure 2.1 ASEP Analytical Framework for the Chehalis River 13

Figure 3.1 Reservoir Inflow, Outflow, and Stage for the Flood Reduction Only Alternative During the 1990 Flood Event..18

Figure 3.2 Reservoir Inflow, Outflow, and Stage for the Multi-purpose Dam Alternative During the 1990 Flood Event.....19

Figure 3.3 Average Monthly Duration of Limited Fish Passage with Upstream Migration Periodicity for Flood Retention Only Alternative, Water Years 1989 to 2012........24

Figure 3.4 Average Monthly Duration of Limited Fish Passage with Upstream Migration Periodicity for Flood Retention Only Alternative with Extra Holding Time for Debris, Water Years 1989 to 2012........25

Figure 3.5 Upstream Migration Stage-duration Curves for Multi-purpose Alternative, WYs 1989 to 2012........27

Figure 4.1 Mean Annual Flow Exceedance: Grand Mound Gage 31

Figure 4.2 Chehalis River Segments (RM and Segment Lengths) Used for Floodplain Inundation Modeling........35

Figure 4.3 Species-level Changes in Salmonid Habitat Potential in the Chehalis Basin Resulting from Water Retention Alternatives Relative to Current Habitat Potential........39

Figure 4.4 Effects of the Flood Retention Alternatives on Upper Chehalis Salmonid Populations........43

Figure 4.5 Example of Simulations Estimating Spring-run Chinook Salmon Spawners Assuming the Continuation of Existing Conditions 45

Figure 4.6 Example of Simulations Estimating Winter-run Steelhead Spawners Assuming the Continuation of Existing Conditions 46

Figure 4.7 Example of Simulations Estimating Coho Salmon Spawners Assuming the Continuation of Existing Conditions46

Figure 4.8 Estimated Number of Spring-run Chinook Salmon Spawners with the Flood Retention Only Dam 47

Figure 4.9 Estimated Number of Spring-run Chinook Salmon Spawners with the Multi-purpose Dam 47

Figure 4.10 Estimated Number of Winter-run Steelhead Spawners with the Flood Retention Only Dam 48

Figure 4.11 Estimated Number of Winter-run Steelhead Spawners with the Multi-purpose Dam 48

Figure 4.12 Estimated Number of Coho Salmon Spawners with the Flood Retention Only Dam........48

Figure 4.13 Estimated Number of Coho Salmon Spawners with the Multi-Purpose Dam........49

Figure 4.14 Example of Box Plot Figure Used to Present Variability of Spawner Number Estimates in SHIRAZ Simulations.49

Figure 4.15 Comparison of Estimated Median Number of Spring-run Chinook Salmon Spawners by Years 2090 to 2099 (*n*=10) in Existing and Dam Alternatives 50

Figure 4.16 Comparison of Estimated Median Number of Winter-run Steelhead Spawners by 2090 to 2099 (*n*=10) in Existing and Dam Alternatives....50
Figure 4.17 Comparison of Estimated Median Number of Coho Salmon Spawners by 2090 to 2099 (*n*=10) in Existing and Dam Alternatives....51
Figure 4.18 Floodplain Area Inundated Under Dam and No-dam Scenarios During a 500-Year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam....63
Figure 4.19 Floodplain Area Inundated for Dam and No-dam Scenarios During a 100-year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam....64
Figure 4.20 Floodplain Area Inundated for Dam and No-dam Scenarios During a 20-year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam....65
Figure 4.21 Floodplain Area Inundated for Dam and No-dam Scenarios During a 10-year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam....66
Figure 4.22 Floodplain Area Inundated for Dam and No-dam Scenarios During a 2-year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam....67
Figure 4.23 Comparison of Water Temperature Below the Proposed Dam Site in the Flood Control Alternatives and Salmon Life History Stages....73
Figure 5.1 Average Air Temperature in Degrees Fahrenheit: Chehalis River at Grand Mound....81
Figure 5.2 Monthly Total Runoff in Inches: Chehalis River at Grand Mound....83
Figure 5.3 Annual Maximum Daily Flow Projections: Chehalis River at Grand Mound....84
Figure 5.4 Annual Minimum Daily Flow Projections: Chehalis River at Grand Mound....85
Figure 5.5 Estimated Habitat Distributions in Grays Harbor under Existing (1981) Conditions....87
Figure 5.6 Estimated Habitat Distributions in Grays Harbor in 2025 (top) and 2050 (bottom) Assuming A1B Maximum Emissions Scenario Projections for Sea Level Rise....88
Figure 5.7 Conceptual Model of Climate Controls on Aquatic Environments....90
Figure 5.8 Basin-wide Effects of Alternative Climate Conditions on Chehalis Basin Salmonids....95
Figure 5.9 Population-level Effects of Alternative Future Conditions on Chehalis Basin Coho Salmon....96
Figure 5.10 Population-level Effects of Alternative Future Conditions on Chehalis Basin Fall-run Chinook....97
Figure 5.11 Population-level Effects of Alternative Future Conditions on Chehalis Basin Spring-run Chinook....98
Figure 5.12 Population-level Effects of Alternative Future Conditions on Chehalis Basin Winter-run Steelhead....99
Figure 5.13 Estimated Number of Spring-run Chinook Salmon Spawners with Climate Change....99
Figure 5.14 Estimated Number of Winter-run Steelhead Spawners with Climate Change....100
Figure 5.15 Estimated Number of Coho Salmon Spawners with Climate Change....100
Figure 6.1 Proportional Changes in Chehalis Basin Salmonids from Current Abundance Due to Riparian Enhancements, Culvert Removal, and Flood Retention Alternatives....106
Figure 6.2 Effect of Combination Scenarios on Chehalis River Coho Salmon Populations....107
Figure 6.3 Effect of Combination Scenarios on Chehalis River Fall-run Chinook Salmon Populations....108
Figure 6.4 Effect of Combination Scenarios on Chehalis River Spring-run Chinook Salmon Populations....109
Figure 6.5 Effect of Combination Scenarios on Chehalis River Winter-run Steelhead Populations....110
Figure 6.6 Effect of Flood Retention Alternatives on Chehalis Basin Salmon Under Alternative Future Conditions....111
Figure 6.7 Effect of Flood Retention Alternatives on Chehalis Basin Coho Salmon Under Alternative Future Conditions 112
Figure 6.8 Effect of Flood Retention Alternatives on Chehalis Basin Fall-Run Chinook Salmon Under Alternative Future Conditions....112
Figure 6.9 Effect of Flood Retention Alternatives on Spring-run Chinook Salmon Under Alternative Future Conditions..113
Figure 6.10 Effect of Flood Retention Alternatives on Chehalis Basin Winter-run Steelhead Under Alternative Future Conditions....114

Figure 6.11 Proportional Changes in Chehalis Basin Salmonids from Current Abundance Due to Climate Change, Habitat Enhancement, and Flood Retention Alternatives 117

LIST OF APPENDICES

Appendix A Analysis of Flood Reduction Alternatives
Appendix B Ecosystem Diagnosis and Treatment Modeling Methods
Appendix C SHIRAZ Modeling Methods

LIST OF ACRONYMS AND ABBREVIATIONS

ASEP	Aquatic Species Enhancement Plan
Basin	Chehalis River Basin
cfs	cubic feet per second
CIG	Climate Impacts Group
Committee	Chehalis Basin Flood Study ASEP Technical Committee
DFO	Department of Fisheries and Oceans Science
Ecology	Washington State Department of Ecology
EDT	Ecosystem Diagnosis and Treatment
FLIR	Forward Looking Infrared Radiometer
FRO	Flood Reduction Only
HEC-RAS	Hydrologic Engineering Center River Analysis System
HSI	Habitat Suitability Index
I-5	Interstate 5
IPCC	Intergovernmental Panel on Climate Change
MF	managed forest
MPD	Multi-purpose Dam
NMF	non-managed forest
NOAA	National Oceanic and Atmospheric Administration
PHABSIM	Physical Habitat Simulation
PIT	passive integrated transponder
Project	Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species Project
RCC	roller compacted concrete
RKm	River Kilometer
RM	River Mile
SHIRAZ	Salmon Habitat Integrated Resource Analysis
SLAMM	Sea Level Affecting Marshes Model
SR	State Route
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife
WFC	Wild Fish Conservancy
WRIA	Water Resource Inventory Areas
WSDOT	Washington State Department of Transportation
WUA	weighted usable area
WY	Water Year

Executive Summary

The Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species Project (Project) is a feasibility-level study of the effects of Flood Reduction Alternatives and habitat enhancement scenarios on key aquatic species habitat and ecosystem processes in the Chehalis River Basin (basin). This report summarizes results of studies on the potential effects of Flood Reduction Alternatives and future climate variability on aquatic resources, and combinations of these alternatives including habitat enhancement alternatives. The companion *Aquatic Species Enhancement Plan* (ASEP) summarizes results of studies on the potential for habitat enhancement actions to benefit these resources.

Studies of the potential effects of Flood Reduction Alternatives and future climate variability on aquatic resources were co-led by Anchor QEA and the Washington Department of Fish and Wildlife (WDFW), and Erik Neatherlin (WDFW) and John Ferguson (Anchor QEA) co-led the study. Analyses were conducted primarily by staff from WDFW and the Anchor QEA consulting team (Anchor QEA, ICF International, Confluence Environmental, and BioAnalysts, Inc.) under the general direction of the State of Washington and the Chehalis Basin Flood Study's ASEP Technical Committee (Committee). Additional staff from the Washington State Department of Ecology (Ecology), the Chehalis Tribe, the Quinault Indian Nation, local water districts, municipalities, and natural resource agencies also contributed to the implementation of the studies. Their input was received during technical workshops, committee meetings, and numerous teleconferences conducted as part of the study. These workshops and meetings resulted in the approach, methods, assumptions, and alternatives used to develop the results presented in this report.

The Chehalis River basin, which covers 2,766 square miles, is the largest river basin in western Washington and one of the only remaining systems that maintains an active connection with the floodplain. It is the largest watershed located entirely within Washington State. Extensive in-channel and off-channel habitats for aquatic species, high salmonid fish species diversity, an endemic species of mudminnow, and the highest species richness of amphibians in Washington State are notable features of the basin. Anthropogenic effects on aquatic species and their habitats have occurred since the 1850s from agricultural practices, logging, in-stream wood removal, gravel mining, urbanization, dredging and filling, dams and diversions, and industrial waste disposal.

To assess the potential effects of Flood Reduction Alternatives and future climate change on aquatic resources, a list of approximately 70 Key Species of fish, invertebrates, mammals, and birds known to occupy Chehalis basin habitats was developed. The list was based on all species known to occupy the basin and consideration of key ecosystem processes and habitat types. Of these, 46 Key Species of selected fish, invertebrates, mammals, and birds are addressed in the text of the ASEP, and 23 had sufficient information to support model studies of the effects of water retention and future climate alternatives on them (Table ES-1). In addition, 5 non-native species were selected to be analyzed because these species may either alter habitat suitability for native species or benefit directly or indirectly from habitat changes resulting from Project alternatives in ways that effect either a guild or individual Key Species.

Table ES-1
Key Species Analyzed in the Aquatic Species Enhancement Plan

KEY SPECIES (COMMON NAME)	SCIENTIFIC NAME	MODELING ALTERNATIVES		
		EDT (E) SHIRAZ (S)	HSI	CORRELATIVE
Salmonids				
Winter-run steelhead	*Oncorhynchus mykiss*	E,S		
Coho salmon	*Oncorhynchus kisutch*	E,S		
Fall-run Chinook salmon	*Oncorhynchus tshawytscha*	E		
Spring-run Chinook salmon	*Oncorhynchus tshawytscha*	E,S		
Other Fish Species				
Chum salmon	*Oncorhynchus keta*		X	
Eulachon	*Thaleichthys pacificus*			X
Pacific lamprey	*Lampetra tridentata*		X	
White sturgeon	*Acipenser transmontanus*		X	
Olympic mudminnow	*Novumbra hubbsi*			X
Speckled dace	*Rhinichthys osculus*			X
Largescale sucker	*Catostomus macrocheilus*			X
Riffle sculpin	*Cottus gulosus*			X
Reticulate sculpin	*Cottus perplexus*			X
Smallmouth bass	*Micropterus dolomieu*		X	
Largemouth bass	*Micropterus salmoides*		X	
Mountain whitefish	*Prosopium williamsoni*		X	
Non-fish Species				
Coastal tailed frog	*Ascaphus truei*			X
Western toad	*Bufo boreas*		X	
Northern red-legged frog	*Rana aurora*			X
Oregon spotted frog	*Rana pretiosa*			X
Dunn’s salamander	*Plethodon dunni*			X
Van Dyke’s salamander	*Plethodon vandykei*			X
North American beaver	*Castor canadensis*			X

Notes:
EDT = Ecosystem Diagnosis & Treatment
HSI = Habitat Suitability Index

Two salmon population habitat models were used to analyze the effects of water retention alternatives and future climate scenarios: Ecosystem Diagnosis & Treatment (EDT) and the Salmon Habitat Integrated Resource

Analysis (SHIRAZ). The EDT model evaluates habitat at a stream-reach scale, and encompassed the entire Chehalis basin upstream of, and including, the Wynoochee River. The EDT model provides a detailed analysis of potential habitat limitations at various reach scales for each salmon species and sub-population in the Chehalis basin. EDT results represent habitat conditions at a discrete point in time defined by the user, and outputs from the model (e.g., salmon abundance, habitat restoration potential) are represented as single data points. The SHIRAZ model uses a less detailed habitat depiction than EDT and stochastically forecasts fish performance into the future by incorporating environmental and population abundance variability into its estimates. In this manner, SHIRAZ provides an estimate of the variance associated with its results. SHIRAZ analyses were limited to salmon populations in the mainstem Chehalis River below the proposed dam site. Studies using the two models were based on different sets of habitat data and were conducted independently. Use of both models allowed for a more comprehensive evaluation of the effects of alternative actions on salmonids. Areas of agreement and disagreement between results of studies using both models helped inform uncertainties and sensitivities in the underlying data and model assumptions.

Flood Reduction Alternatives

Four Flood Reduction Alternatives were evaluated: two water retention facilities (Flood Reduction Only [FRO] and a Multi-purpose Dam [MPD]), a suite of small projects, and protecting Interstate 5 near the twin cities of Centralia and Chehalis. For the purposes of this report, the suite of small projects and the alternatives developed to protect I-5 were qualitatively assessed because it became apparent that the magnitude of their effects to the aquatic environment would be minimal. Therefore, the analyses of Flood Reduction Alternatives focused primarily on the two water retention alternatives.

ALTERNATIVES MODELED

Two water retention alternatives were evaluated: FRO and MPD. The primary differences between the two alternatives from an aquatic resources standpoint are as follows:

- How often each alternative floods stream habitat during flood events
- Whether fish have an opportunity to rear in a reservoir
- Whether flow can be released from the dam for environmental benefits downstream
- The degree to which sediment and wood pass through each alternative to affect geomorphic processes in the channel and floodplain downstream from the dam
- The fish passage facilities required for each alternative

The ASEP authors estimated changes in physical conditions upstream from the proposed dam site and the effectiveness of potential facilities to pass fish associated with each alternative. In addition, changes in physical processes in the mainstem Chehalis River below the dam site in the following categories were incorporated into the analyses: hydrologic regime, water temperature, channel structure and substrate composition, and floodplain inundation.

Under current conditions, the FRO Alternative would involve storing water for short periods of time preventing fish from passing the dam. Two analyses were performed to estimate the time that fish passage would be blocked by the FRO Alternative for flood reduction and debris management operations. Based on the more conservative of these analyses, two additional weeks of flood reduction would be needed to manage debris during large floods. Under this scenario, fish passage at the FRO dam would be blocked an average of 5.4 days per year (1.5% of the time) due to a complete closure of the outlet tunnels. The average duration of time fish passage is blocked when the dam is in operation is 25.8 days (7.1% of the time). In addition, fish passage would be delayed or impaired when flows exceed 2,000 cfs (56.6m3/sec) through the tunnels. This would occur on average an additional 8.9 days per year (2.4% of the time) with the FRO Alternative. In total, fish passage was estimated to be blocked or inhibited an average of 14.3 days (3.9%) per year under the FRO Alternative. In comparison, under natural conditions, flows greater than 2,000 cfs (56.6 m3/sec) would be exceeded an average of 9.9 days per year (2.7% of the time). This results in the FRO Alternative blocking fish passage an additional 5 days per year on average compared to natural condition. In years when the reservoir is being used for flood storage, the duration is much higher (average of 25.8 days), and weighed heavily in the decision to add upstream fish passage facilities to the FRO Alternative.

The reason for the difference in number of days fish passage is impaired under natural conditions (9.9 days per year) and the FRO Alternative (8.9 days per year) at flows great than 2,000 cfs (56.6 m3/sec) is the reservoir would be storing water during some of the time flows exceed 2,000 cfs (56.6 m3/sec).

The length of the reservoir would vary with the flood event, and would be 7 miles (11.2 km) in length at maximum capacity. Between storage events, the reservoir would be evacuated and the river returned to its channel and the unaltered flow regime re-established. However, the channel in this section of the river would be altered by the water retention structure. It would no longer have the same riparian buffer, resulting in a reduction in many attributes. This includes reductions in channel shading from a lack of forested canopy, food inputs, large wood material inputs, resistance to streambank erosion, and filtering of sediments from upland sources. Furthermore, plant and animal communities associated with riparian areas in the footprint of the dam would also be lost. Also, the in-stream channel would lack a typical pool-riffle-run configuration. It would be changed to one that fluctuated between two different states: being sedimented immediately after a water retention event, and then after exposure to flow, it would adjust to a more typical channel structure where sediment deposited in the channel would be mobilized and transported downstream. Water temperatures downstream of the dam would reflect ambient temperatures with the potential for increases over current conditions due to a lack of riparian buffers in the footprint of the dam.

To analyze the effects of the FRO Alternative on salmon, three alternatives were evaluated using EDT. Designated as FRO25, FRO50, and FRO100, these alternatives represented the assumption that 25%, 50% or 100% of the habitat upstream from the FRO dam, respectively, would be degraded as a result of impounding flood flows. These alternatives were developed to evaluate uncertainty associated with how the frequency of FRO use within and between years effected habitat conditions for salmon upstream from the dam. The scenarios differed only in respect to conditions upstream from the dam and were identical with respect to the effect of the FRO Alternative on conditions below the proposed dam. These three FRO Alternatives focused on changes in habitats used by salmon. How FRO Alternatives affect riparian forest and other habitats of aquatic species other than salmon were not assessed at this stage of feasibility.

In contrast, the MPD Alternative would also involve a reservoir approximately 7 miles in length. However, aquatic and terrestrial habitat in the footprint of the dam would be inundated for much of the year, compared to the shorter inundation periods under the FRO Alternative. From spring through late summer, water stored in the conservation pool (65,000 acre-feet) would be released for environmental benefits to increase river flow and cool the mainstem during the low flow season. From a water quality standpoint, assuming sufficient runoff exists in a given year to allow water to be stored for conservation purposes and the reservoir stratifies, colder water could be released from the reservoir through various outlets. During flood events, an additional 65,000 acre-feet of storage would be available for storage in addition to the conservation pool volume of 65,000 acre-feet. The footprint of the MPD Alternative is slightly larger than that of the FRO Alternative. Also, as noted in the *Chehalis Basin Flood Strategy - Combined Dam and Fish Passage Design Technical Memorandum*, providing adequate upstream and downstream fish passage under the MPD Alternative presents greater challenges than does the FRO Alternative.

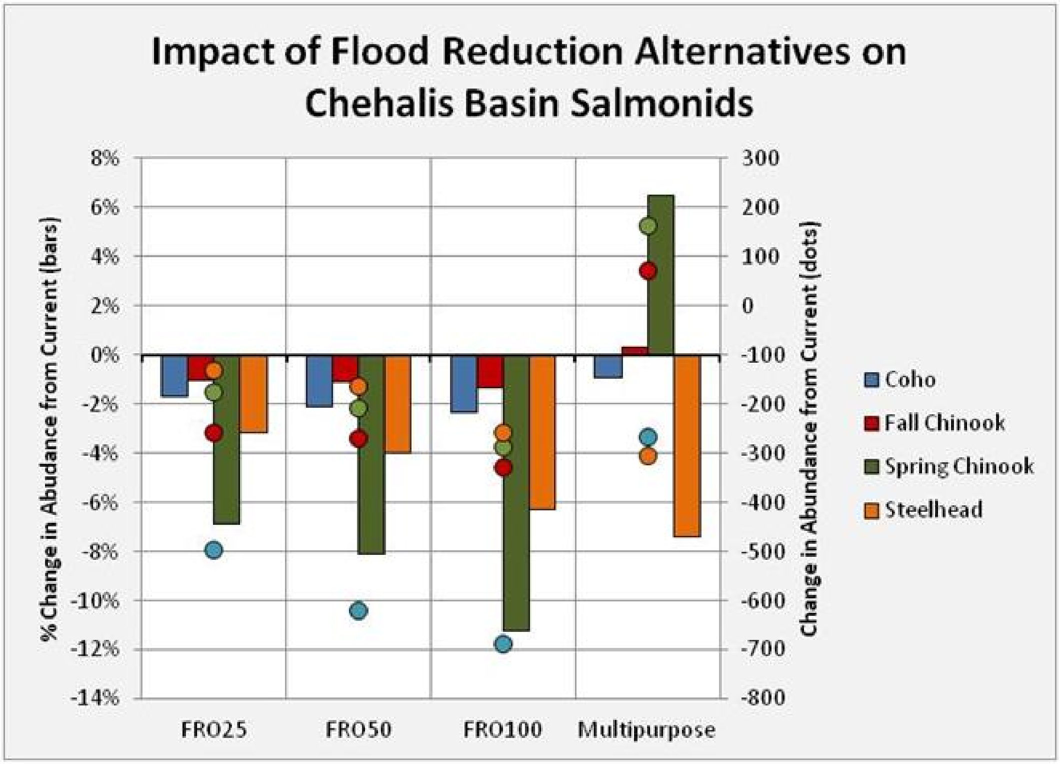
Operations for each water retention alternative were incorporated into the analyses. However, it should be emphasized that these operations, especially for the MPD Alternative, could potentially be refined further to provide additional benefits to aquatic species and address potential effects associated with the climate change scenarios that were evaluated.

RESULTS: EFFECTS ON SALMON

Of the two dam alternatives, the FRO Alternative had negative effects on all species at the basin-wide scale. Also at this scale, the MPD Alternative had negative effects on coho salmon (*Oncorhynchus kisutch)* and winter-run steelhead (*O. mykiss*) but somewhat positive effects on fall-run and spring-run Chinook salmon (*O. tshawytscha*; Figure ES-1). The positive effect of the MPD Alternative on spring-run Chinook salmon, and to a much lesser degree on fall-run Chinook salmon, resulted from a reduction in summer water temperature and scour and an increase in summer flow below the proposed dam. These positive effects on Chinook salmon, however, need to be considered with caution as they are predicated on the assumption that Chinook salmon do not seek and locate cold water refugia in the absence of a dam. Where adult spring-run Chinook salmon hold over summer prior to spawning in the Chehalis system is not known and represents a key uncertainty. Anecdotal empirical information suggests that these salmon are in fact not holding in the area below the proposed dam site. Also, for these positive effects to be realized, runoff must be sufficient in a given year for water to be stored in the conservation pool of the MPD Alternative. However, if the mainstem Chehalis were to provide adequate habitat for spring-run Chinook salmon, where it currently does not, these positive effects should be realized because there would be additional habitat for spring-run Chinook salmon.

Effects on coho salmon and winter-run steelhead resulted from the relatively high assumed passage mortality at the dam site and geomorphic changes below the dam site (reduction in large woody material supply, coarsening of habitat types, reduction in fine sediment and reduction in bed scour).

Figure ES-1
Species-level Changes in Salmonid Habitat Potential in the Chehalis Basin Resulting from Water Retention Alternatives Relative to Current Habitat Potential



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

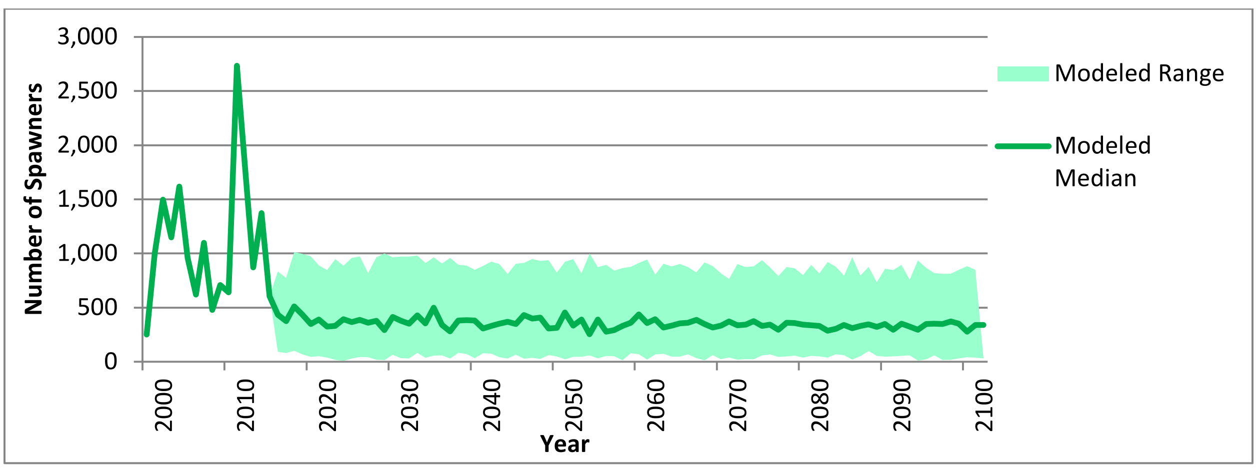
Both dam alternatives lessened flood peaks and thereby reduced off-channel habitat used by juvenile salmon in areas below the dams. However, while both dam alternatives lessened flood peaks, the FRO option did not provide a corresponding positive effect of reduction in water temperature as would occur with the MPD Alternative.

At the sub-population scale, results of EDT model studies varied with species, sub-population, and dam alternative. In general, the FRO Alternative resulted in greater effects to upper Chehalis sub-populations than did the MPD Alternative. For upper Chehalis River sub-populations, the MPD resulted in positive changes in the abundance of spring-run and fall-run Chinook salmon and winter-run steelhead below the dam, and a reduced abundance of all upper Chehalis River sub-populations of coho salmon. The MPD Alternative also resulted in decreases in the Elk Creek and upper Chehalis sub-populations of spring-run and fall-run Chinook salmon and winter-run steelhead. The positive effects of the MPD Alternative reflected a reduction in water temperature below the dam as discussed previously. In contrast, coho salmon spawn considerably later and the MPD Alternative provided no benefit from temperature reductions for upper Chehalis coho salmon sub-populations. For Elk Creek sub-populations, adult fish were assumed in the model to hold in Elk Creek and as such were not exposed to releases of colder water from the MPD Alternative. Juvenile salmon from Elk Creek moved into the mainstem river in the model and were exposed to reduced wood and habitat changes in the mainstem associated with the alternative during spring prior to emigrating from the system. For all sub-populations, abundance was affected by the reduction in large wood, coarsening of habitat types, reduction in fine sediment, and reduction in bed scour.

At the sub-population scale, for middle and lower Chehalis River sub-populations, results were generally similar in their patterns among species as the upper Chehalis River sub-populations but the proportional changes in estimated abundance were smaller and typically decreased with increasing distance downstream from the dam site.

For mainstem-only populations of salmon and based on SHIRAZ, estimated abundance decreased under both water retention alternatives except for spring-run Chinook salmon under the MPD Alternative. For spring-run Chinook salmon, the estimated median number of spawners decreased by 59% under the FRO Alternative and increased by 5% under the MPD Alternative compared to existing conditions. The estimated median number of winter-run steelhead spawners decreased by 32% under the FRO Alternative and by 42% under the MPD Alternative compared to existing conditions. The estimated number of coho salmon spawners decreased by 32% under the FRO Alternative and by 44% under the MPD Alternative. The SHIRAZ model estimated less variability in the number of spawners compared to historic and recent observations, such that high return years would not occur if a dam was in place. As an example of SHIRAZ results, Figure ES-2 shows the pattern and variability in changes to mainstem coho salmon populations under the FRO dam alternative over the simulation period. However, the reduced variability in future population size that was observed under water retention alternatives should be interpreted with caution. Estimates of future conditions were centered on average conditions observed in the past and applied across all variables. In contrast, actual salmon population sizes observed in the past were based on field observations and resulted from the full (not average) range in conditions the population experienced throughout the life cycle.

Figure ES-2
Estimated Number of Coho Salmon Spawners with Flood Reduction Only Dam



Changes in population size predicted by the SHIRAZ model for mainstem salmon population were immediate, after which population numbers were relatively stable for the remainder of the analysis period (years 2020 to 2099; Figure ES-2). Because the range of estimated number of spawners decreased under both dam alternatives, changes in the population sizes predicted were immediate, and spawner abundance was at or near zero more frequently than in the recent calibration period, populations may be more vulnerable under both dam alternatives salmon. The general congruence between the two models (EDT and SHIRAZ) increases confidence in the modeled results.

When the EDT and SHIRAZ results are placed into the context of what is known about existing populations of salmon in the Chehalis basin, they suggest that salmon populations modeled are generally at greater risk under

Flood Reduction Alternatives than current conditions, particularly spring-run Chinook salmon under the FRO Alternatives. Estimated spring-run Chinook salmon spawner abundance in the basin from 1991 to 2013 averaged 2,448 fish, the lowest of the four species analyzed. Their life history of migrating into the river early and then holding for several months exposes them to risk of mortality resulting from high summer water temperatures in the river. However, EDT modeling suggested that upper Chehalis River sub-populations of spring-run Chinook salmon and to a lesser degree fall-run Chinook salmon would benefit from the releases of cool water from the MPD Alternative based on the assumptions modeled. SHIRAZ results concurred with a benefit accruing to mainstem spring-run Chinook salmon populations from the MPD Alternative, which were estimated to increase 5% over existing conditions.

Alternatives to address protecting flooding of I-5 were not explicitly evaluated due to difficulty in quantifying changes at the basin-wide scale of these analyses given that the magnitude of their effects to the aquatic environment were judged to be minimal and the available analytical methods. These projects (raising I-5, bypassing I-5, and protecting I-5 with walls and levees) were not anticipated to have much, if any, measurable effect on aquatic species at the basin-wide scale. Similarly, multiple potential small flood reduction projects identified under the Project were reviewed. However, the designs of the small flood reduction projects were very conceptual at this stage of development. Given this, their assumed localized and small effect on aquatic species, the difficulty in quantifying changes at the basin-wide scale, and the available analytical methods, the small flood reduction projects were not modeled in these analyses.

RESULTS: EFFECTS ON IN-CHANNEL HABITAT FOR OTHER FISH AND NON-FISH SPECIES

Under current (baseline) conditions, Physical Habitat Simulation (PHABSIM) modeling applied to the MPD, not the FRO Alternative. The FRO Alternative was not modeled because the PHABSIM model is configured to model low flow conditions. For the FRO Alternatives, flows during much of the year were outside its range, including all the winter months. Also, flows during the portions of the year that could be modeled were considered to not differ from ambient (no-dam) flows for the FRO Alternative.

Results for current conditions revealed that low flows during the drier summer months appeared to be a limiting factor for several species, but preferable for others. Changes in flow associated with the MPD Alternative resulted in both increases and decreases of habitat for species in this group depending on species and life stage. Most species modeled, including the western toad (*Bufo boreas*), both bass species, largescale sucker (*Catostomus macrocheilus*), and speckled dace (*Rhinichthys osculus*) generally sustained declines in habitat. Two species, mountain whitefish (*Prosopium williamsoni*) and Pacific lamprey (*Lampetra tridentata*), sustained more increases than decreases in habitat across all reaches examined.

Any reductions in in-stream habitat has the potential to contribute to the local or regional extirpation of state or federally sensitive, candidate, or listed species (e.g., the State Sensitive Olympic mudminnow [*Novumbra hubbsi*], the State Endangered western pond turtle (*Clemmys marmorata*), and the State Endangered and Federal Threatened Oregon spotted frog [*Rana pretiosa*]). Further, besides the potential direct loss of breeding habitat within the footprint of the reservoir, an increase in summer base flows has the potential to delay or eliminate breeding for the instream-breeding western toad downstream of the dam. Loss of instream habitat may have some potential to be regained via changes in the operational flows of the dam that are within its operational capacity.

RESULTS: EFFECTS ON OFF-CHANNEL HABITAT FOR OTHER FISH AND NON-FISH SPECIES

The Key Species from Other Fish and Non-fish groups that occupy off-channel habitat in the Chehalis River include Olympic mudminnow, Pacific lamprey, speckled dace, largemouth bass, riffle sculpin (*Cottus gulosus*), reticulate sculpin (*Cottus perplexus*), largescale sucker, northern red-legged frog (*Rana aurora*), Oregon spotted frog, western toad, western pond turtle, and North American beaver (*Castor canadensis*).

Translating water surface elevations at different flood levels into creation and maintenance of off-channel habitat for species dependent on those habitats is difficult and limited by a lack of information on inundation patterns associated with peak flows (e.g., timing, magnitude, periodicity, etc.) and how these patterns influence the creation and maintenance aquatic habitat. Therefore, a correlative model was used that indexed habitat change as a function of inundation. For the purposes of this analysis, any of the Key Species examined that could occupy off-channel habitat such as oxbows and wetlands were considered to require such habitat during at least one life stage, and change in inundation area was assumed to directly reflect change in habitat for Key Species.

The correlative model used to evaluate habitat changes for off-channel species revealed a marked decline in available habitat (i.e., a decrease in inundation) downstream of the either dam alternative at all flood levels modeled (500-, 100-, 20-, and 10-year events) except for the 2-year event. Declines in habitat were most pronounced in reaches nearest to the proposed dam site. Hence, the implementation of dam alternatives will reduce habitat for off-channel utilizing species or life stages, such as juvenile coho salmon, the State Sensitive Olympic mudminnow, the State Endangered western pond turtle, and the State Endangered and Federal Candidate Oregon spotted frog. For state or federally sensitive, candidate, or listed species, reductions in habitat have the potential to increase risk to these species.

Along with native species, non-native species occupying off-channel habitats, such as largemouth bass, could be negatively affected by loss of habitat associated with water retention alternatives as well. As they compete for food and spawning habitat with native fishes and prey on native fishes, this negative effect of habitat reduction could positively benefit native fishes. On the other hand, a decrease in off-channel habitat for all these species would concentrate their presence in remaining off-channel acreage, which would increase pressure of predation on native species. As a consequence, interpretation of the outcome of changes in inundation at this stage of analysis was ambiguous where non-native aquatic predators, especially fishes, are present.

Climate Change

ALTERNATIVES MODELED

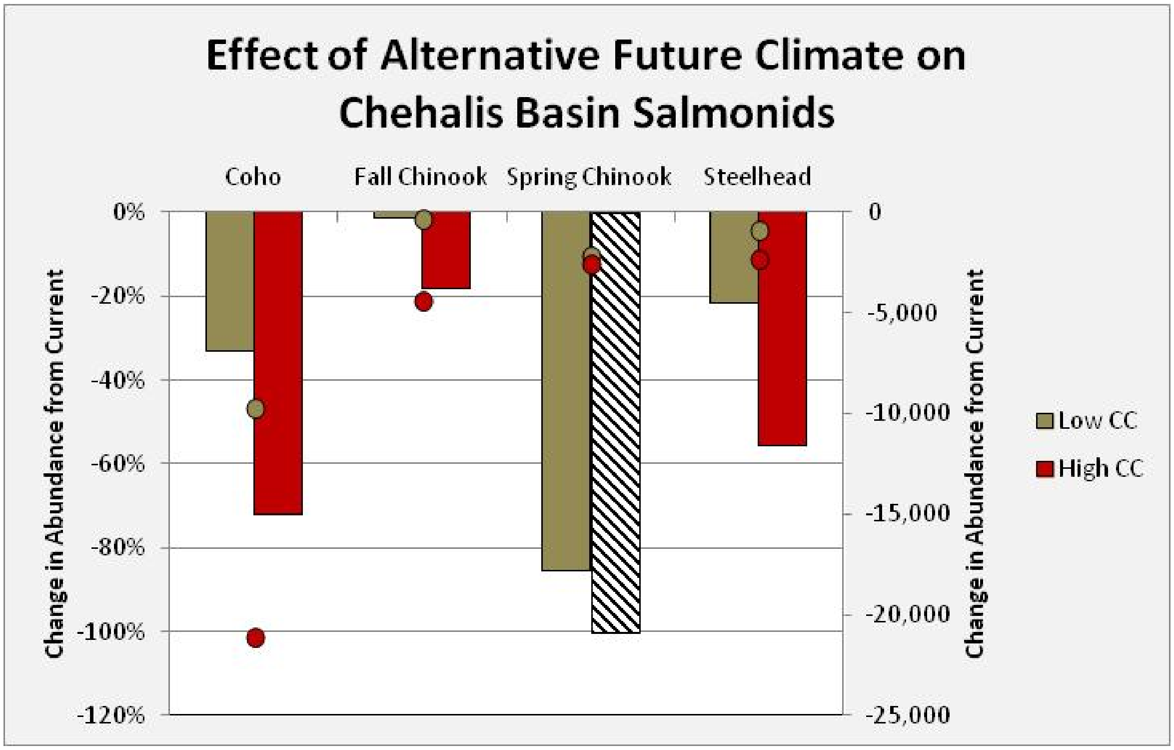
Climate change projections for the region were available from the Climate Impacts Group (CIG) at the University of Washington. The CIG uses multiple models to downscale global projections from the Intergovernmental Panel on Climate Change (IPCC) to smaller geographic areas such as the Pacific Northwest, Washington State, and specific watersheds. Projected changes associated with climate change depend on future projections of greenhouse gas emissions. The climate change projections used in this analysis used projections from the A1B greenhouse gas emissions scenario, where greenhouse gas emissions increase gradually during the 21st century until stabilizing in the final decades. This scenario, which is a moderate-level projection among alternative climate change scenarios, was used to model effects on mainstem salmon populations using the SHIRAZ salmon habitat model and Other Fish and Non-fish Species using the PHABSIM model. For the Other Fish and Non-fish species modeled using PHABSIM, climate change could only be modeled for the summer months due to model limitations.

Additionally, to address the range in potential changes in the Chehalis basin reported in the scientific literature, the effects of two additional climate change scenarios on populations of four salmon species were modeled using the EDT salmon habitat model. These two alternatives were designed to capture a broad range in potential changes in physical processes (flow and water temperature) associated with future climate scenarios. These two alternatives of potential future environmental conditions were characterized as “Low Climate Change” and “High Climate Change” scenarios. The low scenario was designed to reflect changes based on Snover et al. (2013), and where the 100-year flood event is projected to increase an average of 18% at the USGS gage #12027500 Chehalis River at Grand Mound. The high scenario was designed to reflect changes based on recent work by Alan Hamlet (University of Notre Dame), where the 100-year flood event is projected to increase an average of 90% at Grand Mound. The alternatives were based on flow records from 1989 to 2012, where each Water Year (WY) was placed into one of five relative categories: Wet, Normal Wet, Normal, Normal Dry, and Dry. Hydrologic Engineering Center River Analysis System (HEC-RAS) model outputs of WYs selected to represent each category were used to provide quantitative estimates of the flow and channel width changes expected in each WY. All EDT analysis other than the climate change analysis described in this report were based on a HEC-RAS depiction of flow and channel width in the mainstem Chehalis River for the Normal WY condition. Therefore, the Low Climate Change scenario was constructed by combining the HEC-RAS analyses of Normal Wet and Normal Dry WY conditions, consistent with the assumption of wetter winters and drier summers under climate change. The High Climate Change scenario was constructed by combining the HEC-RAS analyses of Wet and Dry WY conditions, consistent with the assumption of much wetter winter and drier summers under climate change. Under both scenarios, no changes to the water retention alternatives were assumed in regard to operations or conditions within the reservoir footprint. Also, numerous parameters in the EDT model were adapted to different flow, channel width, water temperature, and bed scour conditions in the mainstem Chehalis River and its tributaries associated with each future climate scenario.

RESULTS: EFFECTS ON SALMON

Based on EDT, both the High Climate Change and Low Climate Change scenarios effected all salmon species at the basin-wide scale (Figure ES-3). As expected, the High Climate Change scenario resulted in greater effects than did Low Climate Change. These alternatives of future conditions had their greatest effect on spring-run Chinook salmon and their least effect on fall-run Chinook salmon. Spring-run Chinook salmon were extirpated from the Chehalis basin under the High Climate scenario and substantially reduced under the Low Climate scenario. The effects were primarily the result of assumed increases in summer water temperature in the alternative future conditions, which was applied proportionately to all sub-basins in the system. Across all species and sub-populations, the Low Climate Change scenario resulted in a total of four populations among the four species analyzed being extirpated, compared to a total of 14 under the High Climate Change scenario.

Figure ES-3
Species-level Effects of Alternative Climate Conditions on Chehalis Basin Salmonids



Note: Cross hatching indicates extirpated species. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

Based on results of SHIRAZ model studies, estimated numbers of adult spring-run Chinook salmon, winter-run steelhead, and coho salmon residing in the mainstem Chehalis River declined due to climate change based on the A1B greenhouse gas emissions scenario, but the magnitude of the decline varied among species. For spring-run Chinook salmon, the potential effects of climate change were estimated to reduce median returns to zero. The median number of winter-run steelhead was estimated to decrease by 32% with climate change compared to existing conditions. The median number of coho salmon was estimated to decrease by 5% with climate change compared to existing conditions.

RESULTS: EFFECTS ON OTHER FISH AND NON-FISH SPECIES

Climate change is generally anticipated to have negative effects on cold-adapted species and benefit warm-adapted species. Based on PHABSIM modeling for Other Fish and Non-Fish Species, this also appeared to be the case in the Chehalis basin. That modeling projected that climate change as represented by the A1B greenhouse gas emissions scenario would have variable but positive effects on Pacific lamprey, largemouth bass, smallmouth bass, speckled dace, largescale sucker, and western toad spawning and/or rearing habitat. In contrast, climate change substantially reduced both spawning and rearing habitat for mountain whitefish.

Combinations of Alternatives

HABITAT ENHANCEMENT AND WATER RETENTION ALTERNATIVES

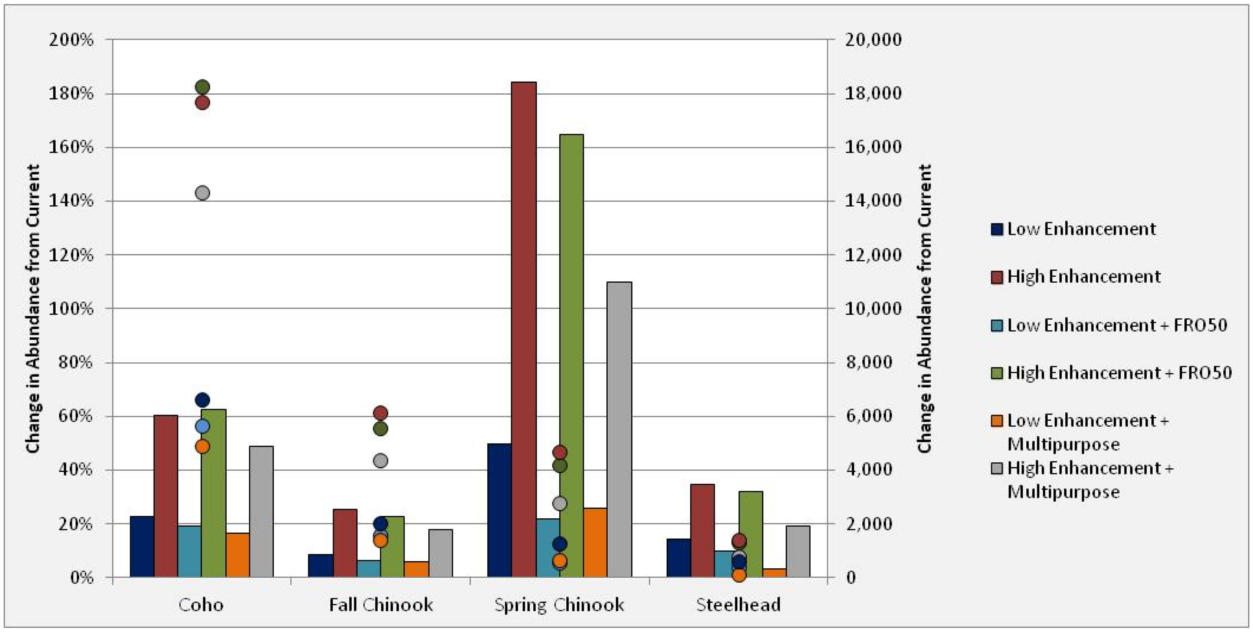
The effects of habitat enhancement alternatives on salmon are described in greater detail in the companion *ASEP Report*. To assess the potential interactions among habitat enhancement and water retention alternatives, Low and High Enhancement scenarios were combined with water retention alternatives and assessed for salmon species using the EDT model. Low and High Enhancement Alternatives were created by combining respectively the Low Enhancement Alternatives for non-managed forest and for managed forest area, and the High Enhancement Alternatives for these areas. Culvert removal was added to and identical between both enhancement alternatives. The Low and High Enhancement Alternatives were then combined with the FRO50 and MPD Alternatives. Results were characterized as both proportional (%) and numerical (absolute) changes in population size.

Results of the combination scenarios are shown in Figure ES-4. Across all species and populations, when dam alternatives were combined with Low and High Enhancement Alternatives, the enhancement measures primarily benefited spring-run Chinook salmon, which were the target of the non-managed forest alternatives. Spring-run Chinook salmon populations in the EDT model responded positively to reductions in temperature associated with both enhancement alternatives. A surprising result of the combination is that High Enhancement combined with the FRO50 Alternative provided a greater benefit to spring-run Chinook salmon and other species than did the High Enhancement combined with the MPD Alternative (Figure ES-4). This is the reverse of the ordering of the two dam alternatives when they were considered individually (i.e., when not combined with habitat enhancement). The reason for this difference was that when enhancement alternatives were combined with the water retention alternatives, it was assumed that the MPD Alternative would override the enhancement conditions upstream and downstream from the proposed dam. For example, it was assumed that enhancement actions would not change the temperature of the MPD reservoir and that temperature below the dam would be the result of dam operations rather than enhancement actions. For the FRO50 and enhancement combination, it was assumed that enhancement would affect temperatures below the dam. To summarize, the High Enhancement Alternative changed key attributes such as temperature to a greater degree when combined with the FRO50 combination, than did the MPD Alternative when combined with enhancement alternatives.

Across all species and populations, adding dam alternatives to the Low and High Enhancement Alternatives generally reduced the benefits of enhancement to populations nearest the dam location and had smaller or no effect on populations further downstream.

Numerically, the combination of High Enhancement and water retention alternatives resulted in the greatest increase in coho salmon (Figure ES-4). The numeric change in the other species was much less, reflecting less change in the case of fall-run Chinook salmon and a much lower level of abundance of spring-run Chinook salmon and winter-run steelhead. Both proportionately and numerically, the proposed flood reduction alternatives reduced the benefits of riparian habitat enhancement, although the resulting abundance was still greater than the abundance under current conditions at the basin-wide scale. Note that for coho salmon, the High Enhancement and FRO Alternative combination produced slightly more fish than did the High Enhancement Alternative alone. This was due variability in HEC-RAS flow data affecting channel width and habitat capacity for coho salmon populations below the dam alternative. The differences in fish abundance between the High Enhancement and FRO Alternative combination and High Enhancement alone are small and were considered to be not meaningful with respect to the overall results.

Figure ES-4
Proportional Changes in Chehalis Basin Salmonids from Current Abundance Due to Riparian Enhancements, Culvert Removal and Flood Reduction Alternatives

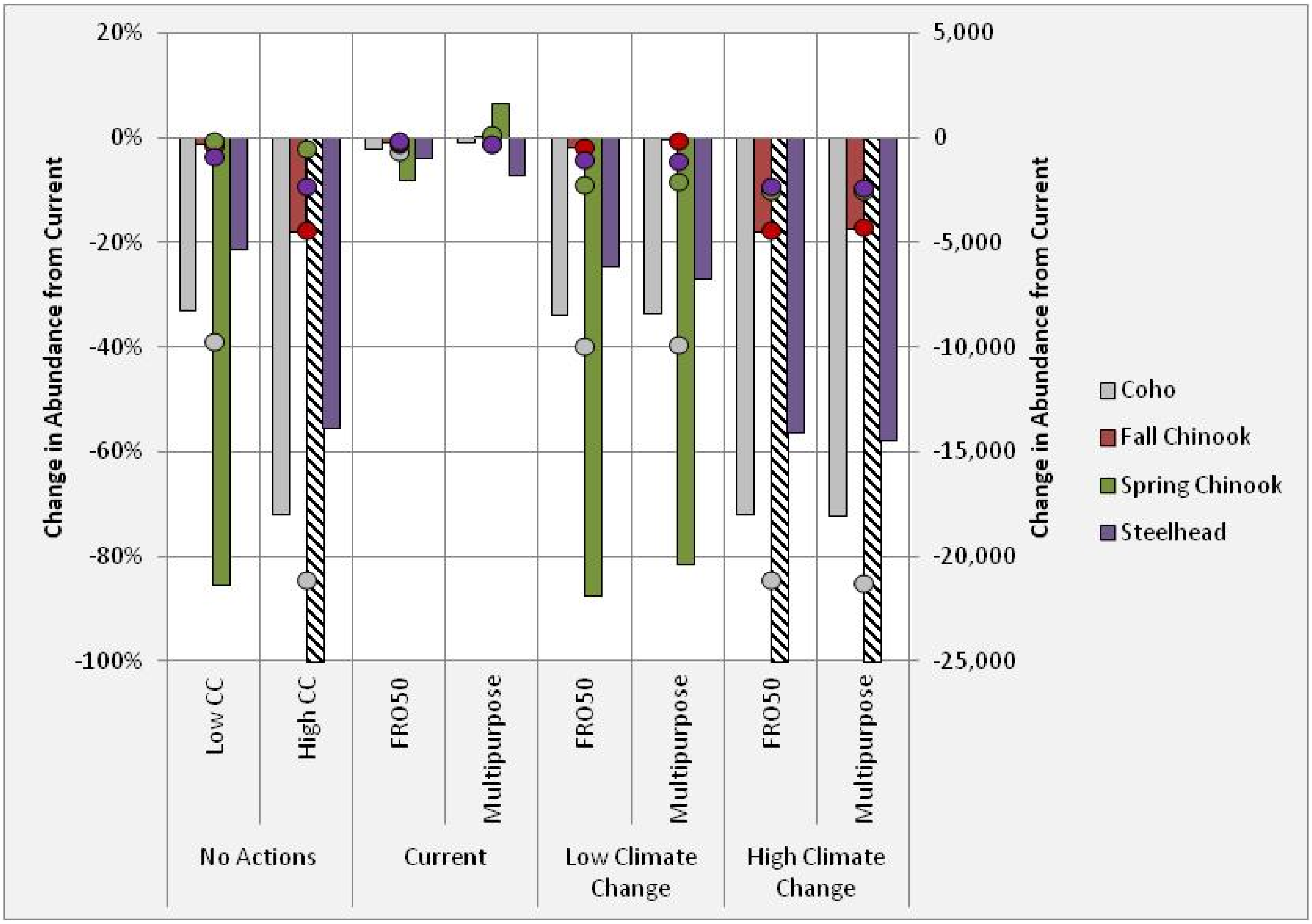


Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

WATER RETENTION AND CLIMATE ALTERNATIVES

Based on EDT, placing water retention alternatives in the watershed under assumptions about future climate change resulted in a range of effects on salmon species. The greatest effects were on spring-run Chinook salmon, and fall-run Chinook salmon were least affected. Effects to coho salmon and winter-run steelhead were intermediate between those of the two runs of Chinook salmon. At the basin scale, the effects of the Low and High Climate Change only scenarios on projected salmon abundance were much larger than the effects of flood reduction alternatives only for all four salmon species (Figure ES-5).

Figure ES-5
Effect of Flood Reduction Alternatives on Chehalis Basin Salmon Under Alternative Future Conditions



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition. The cross-hatched bars represent alternatives under which spring-run Chinook salmon were estimated to be extirpated (100% change in abundance).

Based on EDT, at the sub-population scale, the water retention alternatives generally exacerbated the effects of the climate change scenarios on coho salmon. Under the Low Climate Change and FRO50 combination, the South Fork to the Dam population was extirpated. Under the High Climate Change and FRO50 combination, the South Fork to the Dam and upper Chehalis populations were extirpated. This alternative reduced wood delivery and coarsened habitat downstream from the dam site. The MPD Alternative reduced the effect of the Low Climate Change scenario on the South Fork to Dam population relative to the no-dam situation. In this case, the cooler water from the dam moderated climate change impacts. Under the High Climate Change and MPD Alternative, the South Fork to the Dam and upper Chehalis populations were extirpated.

Fall-run Chinook salmon showed the smallest changes from the water retention alternatives among the four species modeled with EDT, although the changes were not small, especially for sub-populations located nearest to the dam. Under the Low Climate Change and dam combinations, no populations were extirpated under either dam alternative. However, the upper Chehalis fall-run Chinook salmon population was very nearly extirpated under the MPD Alternative and Low Climate Change combination. Under the High Climate Change and dam combinations, three sub-populations of fall-run Chinook salmon were extirpated under both dam alternatives (middle Chehalis Tributaries, Elk Creek, and upper Chehalis). The MPD Alternative moderated the effects of the High Climate Change condition on the South Fork to Dam population in the model due to the release of cold water from the dam.

Spring-run Chinook salmon were affected by both Climate Change Only scenarios to a large degree. When climate change and dam alternatives were combined, the FRO50 alternative had little effect on spring-run Chinook salmon responses except that the condition of the upper Chehalis population was worsened under the Low Climate Change condition and nearly extirpated. Also, when MPD Alternative and the Low Climate Change alternatives were combined, this resulted in the extirpation of the upper Chehalis spring-run Chinook salmon population. Under this combination, the benefits of the cold water releases from the MPD Alternative resulted in an increase in the South Fork to Dam spring-run Chinook salmon population relative to the current abundance, although at a much reduced level relative to the increase estimated to occur under current (i.e., without climate change) conditions. Under the combination of High Climate Change and dam alternatives, spring-run Chinook salmon are extirpated from the basin.

With the FRO50 Alternative, the South Fork to Dam and lower Chehalis Mainstem winter-run steelhead populations were extirpated under both alternative climate conditions. This alternative had the same flow and temperature condition as the no-dam situation, but also assumed that the dam would reduce large wood delivery and coarsen habitats. The MPD Alternative resulted in extirpation of the upper Chehalis winter-run steelhead population under the High Climate Change condition, while this population was reduced by 90% under the Low Climate Change condition. The MPD Alternative also resulted in extirpation of the lower Chehalis Mainstem winter-run steelhead population. However, as with the other species, the MPD Alternative moderated the effect of the alternative future conditions in the South Fork to Dam population due to the release of cold water from the dam.

Based on SHIRAZ model studies, mainstem spring-run Chinook salmon populations are expected to be extirpated under Climate Change Only. This was also the case under the combination of climate change and the FRO dam alternative. However, the MPD Alternative reduced the effect of Climate Change Only on spring-run Chinook salmon by approximately half (a 100% decrease under climate change was reduced to a 49% decrease under the combination of climate change and the MPD Alternative; Table ES-2). These results were based on three factors: the low abundance of spring-run Chinook salmon in the Chehalis basin, their unique life history that makes adults susceptible to elevated water temperatures prior to spawning, and the benefit that releasing cold water from a MPD Alternative would have on augmenting flow and cooling water temperatures during the spring-run Chinook salmon summer holding period. Winter-run steelhead numbers were estimated to decrease with climate change by 62%, and under the combination of dam alternatives and climate change, this value was either unchanged (FRO) or impacted to a somewhat lesser degree under the MPD Alternative (decrease of 49%). Coho salmon showed a slight (5%) decrease in the median number of spawners under climate change, and dam alternatives exacerbated these effects (decreases of 44% [FRO] or 50% [MPD]).

Table ES-2
Estimated Changes to Median Number of Mainstem Chehalis Salmon with Climate Change

SPECIES	CLIMATE CHANGE ONLY	CLIMATE CHANGE WITH WATER RETENTION DAM	CLIMATE CHANGE WITH MULTI-PURPOSE DAM
Spring-run Chinook salmon	-100%	-100%	-49%
Winter-run Steelhead	-62%	-62%	-49%
Coho salmon	-5%	-44%	-50%

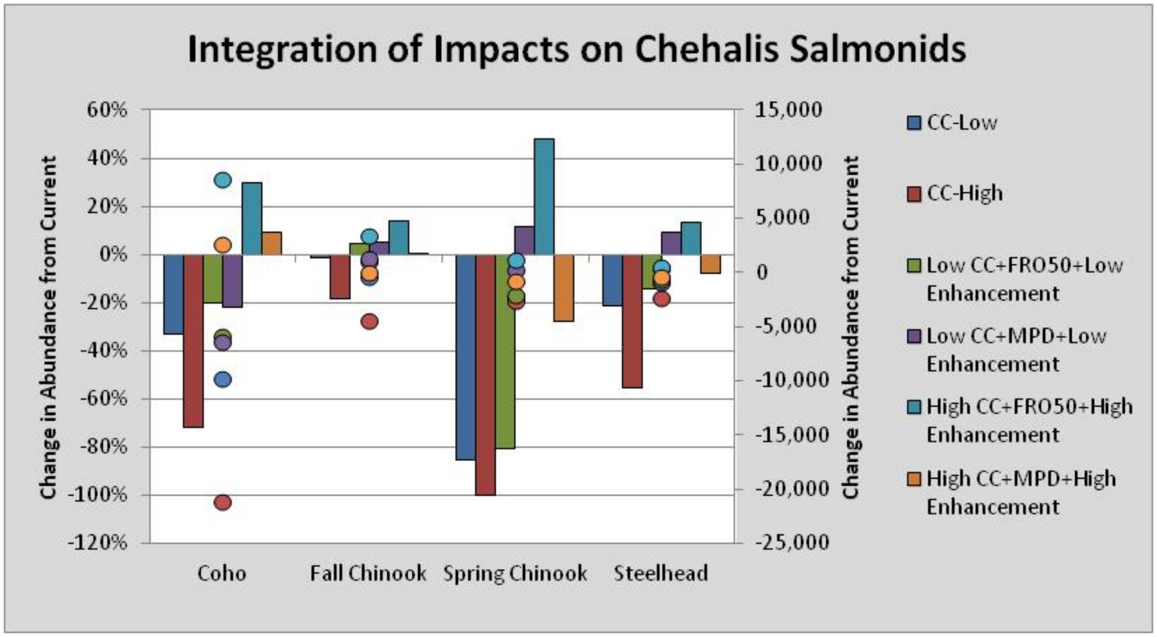
The combination of climate change and operations associated with the MPD Alternative during summer resulted in both increases and decreases to habitat for Other Fish and Non-fish Species, and followed a pattern one would expect based on temperature preferences for the various species. For example, the effects on mountain whitefish spawning and rearing habitat were slightly to highly positive, and rearing habitat was highly improved by the operation of the MPD with climate change due to cooler water being released. For the warm water adapted species (largemouth bass, smallmouth bass, and speckled dace), the effects were generally negative. The effects of the combination of climate change and the MPD on Pacific lamprey varied depending on the life history requirement (spawning or rearing) and reach. Pacific lamprey spawning habitat was improved, but there was a large, negative effect on rearing habitat in the Elk Creek to Newaukum River reach associated with this combination. The effects on largescale sucker spawning and rearing habitat ranged from more negative to highly positive, depending on the life history requirement and reach. The amount of habitat available to the western toad declined with the proposed flows from MPD operations during summer. Across all species and life stages analyzed, the change in modeled habitat (weighted useable area) ranged from -10% to +12%.

HABITAT ENHANCEMENT, WATER RETENTION, AND CLIMATE ALTERNATIVES

To assess the effects of multiple combinations of alternatives on salmon, combinations of climate change, high habitat enhancement, and water retention alternatives were modeled using EDT. The results indicated that under this combination of alternatives, habitat enhancement had to be effective and spatially extensive (i.e., the High Enhancement Alternative had to be used and be successful) to overcome the modeled effects of the High Climate Change Alternative and water retention alternatives (Figure ES-6). Overall and at the basin scale, the effects of both climate alternatives was substantial. Given the apparent large role climate change may have on the Chehalis River ecosystem in the future based on these results, the need for additional studies of the potential effects of climate change in the future was identified in the companion *Data Gaps Report*.

Under this combination of alternatives, the FRO Dam Alternative had greater benefits to spring-run Chinook salmon than did the MPD Alternative. This is the reverse of the results when water retention alternatives were considered individually without habitat enhancement or climate effects. This resulted from assumptions made about whether water temperature below a dam would be controlled by outflow from a dam or habitat enhancement actions downstream of the dam. It was assumed that the increased summer outflow of cooler water from the MPD Alternative would control temperature, whereas habitat enhancement affected temperatures below the dam in the FRO Alternative. The effect of this assumption was almost entirely confined to the mainstem spring-run Chinook salmon population between the South Fork and the proposed dam site. This also resulted in temperature changes and estimated salmon abundance associated with the High Climate Change combined with FRO50 and the High Enhancement Alternative being greater than the temperature changes and estimated salmon abundance due to the High Climate Change combined with MPD and High Enhancement for all four salmon species.

Figure ES-6
Proportional Changes in Chehalis Basin Salmonids from Current Abundance
Due to Climate Change, Habitat Enhancement, and Flood Reduction Alternatives



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

Data Gaps and Scientific Uncertainty

The companion *Data Gaps Report* identifies data gaps in four categories: Key Species and Habitats, physical modeling, climate change, and watershed restoration planning. These gaps should be addressed if the Project proceeds into the next phase of implementation.

Two key data gaps associated with water retention alternatives and climate change are identified in the *Data Gaps Report*. First, under current conditions, the survival of juvenile and adult fish passing the FRO Alternative and the effectiveness of fish passage facilities associated with the alternative were estimated and incorporated into model studies of the effects of the FRO Alternative on salmon. However, the lack of passage when water was impounded was considered to be small due to the frequency of impoundment and time of year and was not incorporated into the analyses. Also, the time required to manage debris was not determined until late in the Project and was not incorporated into the model studies of its effects on salmon, but was addressed in the Project by adding the cost of additional fish passage facilities to the FRO Alternative. These facilities consisted of an adult trap and collection facility below the FRO dam and the means to transport collected fish above the dam. In the future, the time required to impound water and conduct debris management activities under the FRO Alternative in combination with a trap and haul facility being installed should be analyzed as to its effects on aquatic resources in the basin. Because trap and haul facilities have now been incorporated into the FRO Alternative and should improve fish passage conditions relative to what was modeled (a FRO dam without these additional facilities), the effects of the FRO Alternative reported here will likely be reduced when analyzed in the future.

Second, two additional scenarios related to climate change analyzed late in the Project were not incorporated into model studies of the effects of the FRO Alternative on salmon. The first scenario was an 18% increase in peak flows in the Chehalis River and the second was a 90% increase. The amount of time fish passage at the FRO Alternative would be blocked due to water being impounded and debris management activities, and impaired to due to flows exceeding the 2,000 cfs (cubic feet per second [56.6m^3/sec]) design limit of the fish passage conduits in the dam were estimated to increase under both future climate scenarios (Anchor QEA 2014b). These effects were addressed in the Project by adding the cost of additional fish passage facilities to the FRO Alternative as described above. However, the potential effects of these climate scenarios on the operations of the FRO Alternative in combination with a trap and haul facility being installed should be incorporated into future analyses of the FRO Alternative on aquatic resources in the basin.

In terms of scientific uncertainty, variability and uncertainty associated with model outputs are key aspects of interpreting model results. However, quantifying the variability associated with model outputs was not possible for most of the analyses conducted on water retention alternatives and climate change. The exceptions to this included additional EDT runs (e.g., Flood Reduction Only alternatives [FRO25, FRO50, and FRO100] and High and Low Climate Change scenarios) and stochastic simulations of future population sizes of some salmon species using SHIRAZ. Thus, the majority of the results presented throughout this report implies a certain level of precision, but typically have no estimate of the variance associated with each result.

Collectively, the results presented in this report represent the likely effects to aquatic species in the basin from water retention and climate alternatives, and combinations of these alternatives with habitat enhancement alternatives. The results are based on the best information and analytical methods that are currently available. The models generally reflect a scientific understanding of processes on a qualitative level, but quantitative components of the models and interactions of the components of the models are subject to greater uncertainty. Further refinement of modeling at several levels could substantially modify some findings. The companion *Data Gaps Report* was developed to address many of these uncertainties, the need for reduced uncertainty, and the need for decision makers to have a better understanding of remaining uncertainties associated with model outputs in the future.

Finally, some alternatives were combined to provide additional information for decision makers. However, the aforementioned concerns may become compounded when individual model scenarios are combined to inform their potential combined effect on aquatic species. At this time, no way exists to characterize the added variability and uncertainty associated with assumptions about one alternative being combined with assumptions about another alternative.

Key Findings

The following list presents the key findings of this study:

- Effects of all dam alternatives were generally negative upstream and downstream from the dam site on salmon, steelhead, and Other Fish Species. The one exception was positive effects of the MPD Alternative on spring-run Chinook salmon due to cool water released below the proposed dam. This effect, however, is predicated on the assumption that spring-run Chinook salmon currently hold in the warm water below the proposed dam site at sites near where they spawn rather than seeking cold water refugia. Under this assumption, in the model they are dying before spawning and would benefit from cold water released from a storage facility. This key assumption needs to be tested and verified with empirical data in any future work.
- When the EDT and SHIRAZ results are placed into the context of what is known about existing populations of salmon in the Chehalis basin, they suggest that the salmon populations modeled are generally at greater risk under FRO Alternatives than current conditions, particularly spring-run Chinook salmon.

- Based on PHABSIM model studies, stream flow was found to be more limiting in the upper Chehalis River reaches than lower reaches for non-salmonid (Other Fish) species. Also, low flows during the drier summer months appeared to be a limiting factor for several species. Given the importance of flow and the currently poor understanding of non-salmonids (other fishes) in the basin, additional data are needed to corroborate these modeled findings.
- Most non-salmonid species modeled, including the western toad, small and largemouth bass, largescale sucker, and speckled dace generally sustained declines in habitat in response to all modeled dam alternatives. However, there were both increases and decreases in modeled habitat depending on the species and life stage. It is important to note that very little is known about non-salmonid aquatic and semi-aquatic (e.g., amphibian) species in the basin and more information is needed to support more detailed analyses in the future.
- In general, results of model studies indicated that all modeled dam alternatives reduced off-channel habitat, which would result in negative effects on semi-aquatic species.
- The current modeled results suggest that climate change will lead to a major decline for all salmon and steelhead and the extirpation of spring-run Chinook salmon in the basin. Given the severity and potential implications of these results, a more in-depth climate change risk assessment is warranted. Any future work should incorporate climate change as a major component of the analysis.
- Results of combining habitat enhancement and dam alternatives suggested that the combination was positive for salmon and steelhead, and the relative benefit was strongest for spring-run Chinook salmon. Partly this was because some of the enhancement actions targeted spring-run Chinook salmon. Enhancement actions focused on other species will produce somewhat different results. However, the magnitude and/or specificity of these benefits should be interpreted with caution because of the need to test and validate some of the key assumptions about the interactions between enhancement and dam effects.
- Based on EDT and SHIRAZ modeled results, placing flood reduction structures in the watershed exacerbated the negative effects of climate change, leading to the extirpation of several salmonid sub-populations in the basin. The MPD Alternative did reduce the effects from climate scenarios on spring-run Chinook salmon, and to a lesser extent, on winter-run steelhead. However, for spring-run Chinook salmon these results were predicated on the assumption that salmon will not seek and locate cold water refugia in the absence of a dam.
- Based on EDT modeled results, when habitat enhancement, dam alternatives, and future climate scenarios were combined, enhancement had to be effective and extensive (i.e., the High Enhancement Alternative) to overcome the effects of future climate scenarios and dam alternatives.

1 Introduction

1.1 Introduction

The Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species Project (Project) is a feasibility-level study of the benefits and effects of alternatives for flood reduction and a basin-wide assessment of enhancement opportunities for aquatic species. The Flood Reduction Alternatives include water retention on the upper Chehalis River, levees, and other structures along Interstate 5 (I-5), a suite of smaller flood protection projects throughout the Chehalis River basin (basin), and a survey of structures in the floodplain and the effects of flood events on these structures. The enhancement study will evaluate options for improving habitat for aquatic and semi-aquatic species within the basin. The Project will provide information needed by the Chehalis Basin Work Group and regional stakeholders to determine whether to advance the Project to the next phase of study.

This report summarizes results of studies that evaluated the potential effects of water retention alternatives and future climate variability on key aquatic resources in the basin. The companion report, the *Aquatic Species Enhancement Plan* (ASEP), focuses on the status of aquatic resources in the Chehalis basin and the potential for habitat enhancement actions to improve conditions for these resources. The ASEP also provides an introduction to the basin, the species assessed, and how these species were selected. The companion *Data Gaps Report* identifies aspects of the analysis of the effects of water retention, habitat enhancement and climate alternatives on aquatic species and the habitats they rely on that warrant further study in the future.

1.2 Purpose

The studies undertaken in this report reflect a step-wise analytical approach, where the best available scientific data and analytical methods available were used to document the existing aquatic resources in the Chehalis basin and assess factors contributing to the viability of key populations. Based on this technical foundation, future habitat conditions for key aquatic species was estimated for Flood Reduction Alternatives and changes in the ecosystem related to climate change.

1.3 Scope

The analyses focused on three categories of organisms: EDT modeled salmonid fish species, Other Fish Species, and Non-fish Species. These three categories represent more than 70 Key Habitats and Species in the basin as identified by the Washington Department of Fish and Wildlife (WDFW).

The spatial scope of this aquatic species analysis was broad. All tributaries that flow into the Chehalis River upstream from and including the Wynoochee River were included in the analysis, which encompassed most of Water Resource Inventory Areas (WRIA) 22 and all of WRIA 23. Rivers west of the Wynoochee River that flow directly into Grays Harbor (the Wishkah, Hoquiam, and Humptulips rivers) were not included in the analyses because they were not likely to be affected by any proposed flood reduction alternatives located in the uppermost part of the watershed, nor did they have a direct impact on the Chehalis River.

Spatially, the analysis of Flood Reduction Alternatives focused on changes to mainstem Chehalis River habitat and aquatic species that depend on those habitats and the analysis of future climate variability focused on all areas of the basin upstream from and including the Wynoochee River. Temporally, these analyses extended to year 2099 for some salmon populations. Salmon populations were analyzed using the Ecosystem Diagnosis & Treatment (EDT) and Salmon Habitat Integrated Resource Analysis (SHIRAZ) habitat models. The potential effects of Flood Reduction Alternatives and climate change on Other Fish and Non-fish Species were evaluated using Habitat Suitability Index (HSI) and Physical Habitat Simulation (PHABSIM) models when supported by appropriate data, and correlative models where insufficient data existed for HSI or PHABSIM analyses.

1.4 Implementation

Analyses were conducted primarily by staff from WDFW and the Anchor QEA consulting team (Anchor QEA, ICF International, Confluence Environmental, and BioAnalysts, Inc.) under the general direction of the State of Washington and the Chehalis Basin Flood Study's ASEP Technical Committee (Committee). Erik Neatherlin (WDFW) and John Ferguson (Anchor QEA) co-led the study. Additional staff from the Washington State Department of Ecology (Ecology), the Chehalis Tribe, the Quinault Indian Nation, local water districts, municipalities, natural resource agencies, and the Committee also contributed to the implementation of the studies presented in this report.

1.5 Overview of the Chehalis Watershed

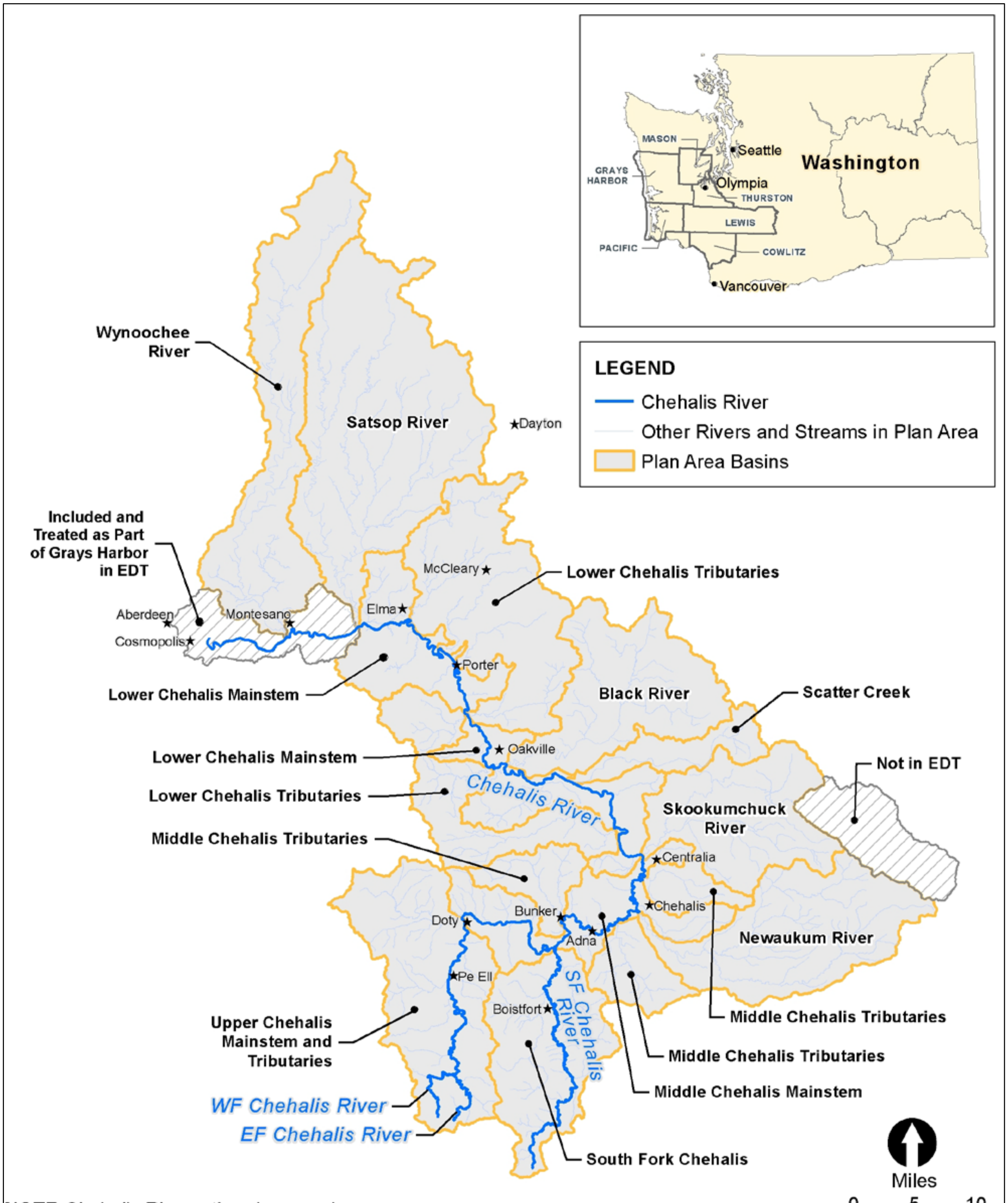
The Chehalis basin is the largest river basin in western Washington State. It encompasses large portions of Grays Harbor, Lewis, and Thurston counties, as well as smaller parts of Mason, Pacific, and Cowlitz counties. It is the largest watershed entirely within state borders and encompasses 2,766 square miles.

Based on average annual discharge, the largest tributaries are the Satsop River (1,968 cfs [55.7 m^3/sec]), Humptulips River (1,344 cfs), Wynoochee River (1,316 cfs), Skookumchuck River (540 cfs [15.3 m^3/sec]), Newaukum River (506 cfs [14.3 m^3/sec]), Cloquallum Creek (375 cfs [10.6 m^3/sec]), and the Black River (330 cfs [9.3 m^3/sec]; Pickett 1992). In total, 1,391 streams with 3,353 linear stream miles (5,396 stream km) exist in the basin (Phinney and Bucknell 1975).

The mainstem Chehalis River is formed by the confluence of the East Fork Chehalis River with the West Fork Chehalis River at River Mile (RM) 118.9 (191.4 RKm; Phinney and Bucknell 1975). The headwaters for the mainstem Chehalis River are in the central Willapa Hills above the town of Pe Ell, Washington. Tributaries to the Chehalis River arise from diverse sources, such as the Olympic Mountains, the Bald Hills, the Willapa Hills, the Black Hills, and a spur of the Cascade Mountain Range (Smith and Wenger 2001). The Chehalis River flows through three distinct eco-regions before emptying into Grays Harbor near Aberdeen: 1) the Cascade ecoregion (including the Olympic Mountains), characterized by volcanic/sedimentary bedrock formations; 2) the Puget Lowland, characterized by glacial and alluvial sediment; and 3) the Coast Range, characterized by volcanic/sedimentary bedrock (CBP 2004).

Based on WDFW spawner survey data and the EDT model (Figure 1.1), an estimated 1,568 stream miles (2,523 stream km) in the basin are currently used by salmon for spawning and rearing. The Satsop River has the most stream miles available to salmon (208.2; 335.1 km), followed by the Newaukum River (182.0; 292.9 km), South Fork Chehalis River (136.7; 220.0 km), Wynoochee River (132.5; 213.2 km), and Skookumchuck River (106.2; 170.9 km). A total of 55.6 stream miles of habitat are available to salmon upstream the proposed dam site, located above the town of Pe Ell, Washington (RM 108; 174 RKm), which is 3.5% of the overall habitat available to salmon in the basin.

Figure 1.1
The Chehalis River Basin



NOTE: Chehalis River, other rivers and streams, and plan area basins provided by ICF.

The Chehalis River has the most extensive off-channel habitats (e.g., oxbows) in its main-channel floodplain of any river in the Pacific Northwest (Vadas 2014), especially on the lower Chehalis floodplain (Miller 1993; Henning 2004) downstream from the town of Elma, Washington. As in most rivers, development of off-channel habitat in the main-channel Chehalis River is progressively more extensive moving in a downstream direction, and is the most developed in two areas: 1) the lower Chehalis River, and 2) between the mouths of the Black and Skookumchuck rivers. By comparison, the main channel of the Willamette River, which in many areas has a broader floodplain, has lost the majority of its off-channel habitat to diverse land uses (Benner and Sedell 1997) and the processes that contribute to off-channel habitat formation have been almost entirely compromised (Dykaar and Wigington, Jr. 2000).

The upper Chehalis River mainstem flows northerly and is unusual in having the combination of a confined channel with a moderate-to-low gradient (Weyerhaeuser 1994). The land use in this headwater area is predominately forest. As the mainstem flows through the areas of Pe Ell and Doty, the direction of flow changes to easterly. As the Chehalis River approaches its confluence with the Newaukum River, the floodplain broadens and turns again to flow in a northerly direction. From Pe Ell to the City of Chehalis, Washington, land use adjacent to the mainstem is dominated by agriculture. Urban and industrial use predominates as the mainstem flows through the area near the twin cities of Centralia and Chehalis, where the river channel has become incised. Additionally, the floodplain becomes markedly constricted just upstream of the city of Centralia, Washington and the confluence with the Skookumchuck River, prior to re-expanding into a larger floodplain downstream.

Near Scatter Creek the mainstem river channel turns to flow in a westerly direction through an area of low prairie land that has experienced residential development. Downstream of Porter, Washington, where flow is in a westerly direction, the Satsop River enters the mainstem Chehalis River. From the town of Montesano, Washington westerly to the mouth of the Chehalis River, the mainstem channel is tidally influenced and comprises numerous sloughs and side channels (Ralph et al. 1994).

The 2007 flood had a profound effect on the Chehalis River system that will persist for decades. The flood resulted in deposition of channel-filling gravels upstream of RM 104 (167.4 RKm), large log jams that caused a channel avulsion near RM 104.5 (168.2 RKm), and overbank wood and fine sediment deposits up to 6 feet deep in unconfined reaches. The gravel deposits upstream of RM 104.5 (168.2 RKm) resulted in substantial fining of the substrate and currently provide excellent spawning areas for resident and anadromous fish. Through time, these deposits will be re-worked and transported downstream until the river reaches a dynamic equilibrium with the bed material, resulting in coarser substrate in much of the upper watershed similar to conditions that existed prior to the 2007 flood (Watershed GeoDynamics and Anchor QEA 2014). The overbank wood deposited on the floodplain and in-channel log jams from the flood were subsequently removed, and these sources of wood for channel-forming processes eliminated from the system.

1.6 Selection of Key Species

The process used to identify Key Species for this analysis is described in greater detail in the companion ASEP. To assess the potential effects of Flood Reduction Alternatives and future climate change on aquatic resources, a list of approximately 70 Key Species of fish, invertebrates, mammals, and birds known to occupy basin habitats was developed. The list was based on all species known to occupy the basin and consideration of key ecosystem process and habitat types. Of these, 46 Key Species of selected fish, invertebrates, mammals, and birds were addressed in the text of the ASEP, and 23 had sufficient information to support model studies of the effects of water retention and habitat enhancement alternatives on them (Table 1.1). In addition, 5 non-native species were selected to be analyzed because these species may either alter habitat suitability for native species or benefit directly or indirectly from habitat changes resulting from Project alternatives in ways that effect either a guild or individual Key Species. Key Species were selected according to the following criteria:

- The species is of conservation, commercial, recreational, or cultural concern.
- The species is likely to be affected by the proposed Flood Reduction Alternatives.
- Adequate data are available for comparison among Flood Reduction Alternatives.
- The species was tied directly to a Priority Habitats identified by WDFW, that is, they represent the habitat directly.

Assessing the potential effects of Flood Reduction Alternatives and climate change on Key Species individually was impractical given available data and schedule. Such an approach could not efficiently identify the groups of species that respond similarly based on their ecological requirements. For these reasons, a coarse-filter/fine-filter approach was developed to organize the examination of changes to ecosystem structure, function, and processes. Fine filter approaches focus on individual species, and are expensive and impractical for species for which information is lacking. Moreover, conserving habitat for listed threatened and endangered species is also complex, commonly involving multiple species and habitats.

Coarse-filter conservation has been supported as a solution to some of the problems associated with fine-filter methods. It attempts to address conservation requirements of many species without necessitating individual species conservation plans (Thompson and DeGraaf 2001). Coarse-filter approaches protect ecosystem linkages and processes, not just species and immediate habitats (i.e., ecosystem structures, functions and processes).

The coarse-filter approach used in this assessment identified important, relatively large-scale ecological elements (ecological community types, ecosystems, or landscapes), and then determined the status (quantity, quality, distribution, etc.) of those types so they could be compared individually or in combination to a standard or benchmark. The large-scale ecological elements identified as "macrohabitats" represented the initial habitat level used to assign species into assemblages, or "macroguilds," where the benchmark was the current (i.e., pre-dam) condition in the basin.

The fine-filter aspect of the approach was done formally for the in-stream macrohabitat, one of two macrohabitats containing most of the species for which responses to dam alternatives were modeled. More than one guild level was defined for the in-stream macrohabitat because the complexity and resolution of information for that habitat allowed this to be done, and because it was the only macrohabitat for which the modeled species responses to dam alternatives needed to be refined. Limited data on the second focal macrohabitat, off-channel/low-flow habitat, especially in comparison to the in-stream macrohabitat, led all the species or life stages of species utilizing that habitat to be grouped into one macroguild. Note that guild organization is not absolute because some species (e.g., western toad) or different life stages of the same species (e.g., coho salmon [*Oncorhynchus kisutch*]) can and do occur in different guilds.

The process of assigning species and habitat to guilds resulted in numerous associations and guild types. To simplify this guild structure, information was organized into the following categories of guilds:

- Salmon species and runs
- Other Fish Species
- Non-fish Species

Table 1.1 identifies the Key Species and how they were grouped and analyzed.

Table 1.1
Key Species Analyzed in the Aquatic Species Enhancement Plan

KEY SPECIES (COMMON NAME)	SCIENTIFIC NAME	MODELING ALTERNATIVES			REPRESENTATIVE SOURCES
		EDT (E) SHIRAZ (S)	HSI	CORRELATIVE	
Salmonids					
Winter-run steelhead	*Oncorhynchus mykiss*	E,S			Withler 1966; Leider et al. 1986
Coho salmon	*Oncorhynchus kisutch*	E,S			Sandercock 1991; Quinn and Peterson 1996
Fall-run Chinook salmon	*Oncorhynchus tshawytscha*	E			Taylor 1990; Healey 1991; Waples et al. 2004
Spring-run Chinook salmon	*Oncorhynchus tshawytscha*	E,S			Taylor 1990; Healey 1991; Waples et al. 2004
Other Fish Species					
Chum salmon	*Oncorhynchus keta*		X		Neave 1966; Salo 1991; Minakawa and Gara 1999
Eulachon	*Thaleichthys pacificus*			X	Mallette 2012; DFO 1999
Pacific lamprey	*Lampetra tridentata*		X		Stone and Barndt 2005; Gunckel et al. 2009
White sturgeon	*Acipenser transmontanus*		X		Parsley and Beckman 1994; Paragamian et al. 2001
Olympic mudminnow	*Novumbra hubbsi*			X	Mongillo and Hallock 1999; Henning et al. 2007
Speckled dace	*Rhinichthys osculus*			X	Batty 2010; Andrusak and Andrusak 2011

KEY SPECIES (COMMON NAME)	SCIENTIFIC NAME	MODELING ALTERNATIVES			REPRESENTATIVE SOURCES
		EDT (E) SHIRAZ (S)	HSI	CORRELATIVE	
Largescale sucker	*Catostomus macrocheilus*			X	McCart and Aspinwall 1970; Dauble 1986; Scoppettone 1988
Riffle sculpin	*Cottus gulosus*			X	Baltz et al. 1982; Moyle and Baltz 1985
Reticulate sculpin	*Cottus perplexus*			X	Henning et al. 2007
Smallmouth bass	*Micropterus dolomieu*		X		Edwards et al. 1983; Sowa and Rabeni 1995
Largemouth bass	*Micropterus salmoides*		X		Stuber et al. 1982; García-Berthou 2002
Mountain whitefish	*Prosopium williamsoni*		X		
Non-fish Species					
Coastal tailed frog	*Ascaphus truei*			X	Adams and Bury 2002; Hayes et al. 2006
Western toad	*Bufo boreas*		X		Deguise and Richardson 2009; Bartelt et al. 2010
Northern red-legged frog	*Rana aurora*			X	Hayes et al. 2008; Adams et al. 2011
Oregon spotted frog	*Rana pretiosa*			X	Pearl and Hayes 2004; Cushman and Pearl 2007
Dunn's salamander	*Plethodon dunni*			X	Wilkins and Peterson 2000; Kluber et al. 2008
Van Dyke's salamander	*Plethodon vandykei*			X	Wilkins and Peterson 2000; Kluber et al. 2009
North American beaver	*Castor canadensis*			X	Naiman et al. 1988; Burns and McDonnell 1998

With the exception of the largemouth and smallmouth bass (*Micropterus salmoides* and *M. dolomieu*, respectively) in the in-stream macrohabitat, responses of non-native species to Project alternatives were not modeled. However, non-native species may alter habitat suitability for native species, or benefit (directly or indirectly) from habitat changes resulting from Project alternatives in ways that effect either a guild or individual Key Species. For this reason, non-native species were integrated into the analyses as potential stressors that could modulate the responses of either a guild or individual species resulting from the aforementioned habitat modeling. Non-native species known to occur within the Project area for which effects have been unequivocally demonstrated were addressed (Table 1.2).

Table 1.2
List of Non-native Species Evaluated in the Aquatic Species Enhancement Plan

SPECIES (COMMON NAME)	SCIENTIFIC NAME	DATA RICHNESS	AFFECTED NATIVE SPECIES	SOURCES
Fishes				
Bluegill	*Lepomis macrochirus*	M	Northern red-legged frog	Adams et al. 2003
Smallmouth bass	*Micropterus dolomieu*	M	Northern red-legged frog	Kiesecker and Blaustein 1998
Largemouth bass	*Micropterus salmoides*	M	Olympic mudminnow, Western pond turtle	Beecher and Fernau 1982; Henning et al. 2007; Holland 1994
Amphibians				
American bullfrog	*Lithobates catesbeianus*	M	Northern red-legged frog, Western pond turtle	Holland 1994; Kiesecker and Blaustein 1997, 1998; Kiesecker et al. 2001; Adams et al. 2003; Adams and Pearl 2007
Plants				
Reed canarygrass	*Phalaris arundinacea*	M	Oregon spotted frog	Kapust et al. 2012

1.7 Effects of Flood Hazard Reduction Structures on River Ecosystems

Many animal species migrate in response to habitats that vary spatially and temporally, including fishes. Furthermore, approximately 1% of the world's fish species use specialized physiological adaptations to migrate between freshwater and marine habitats (McDowell 1988). Most of these are anadromous where individuals spawn in freshwater and become sexually mature in marine habitats (Quinn 2005), presumably to take advantage of higher foraging success and growth rates found in marine waters (Northcote 1978). Migrations of fishes within river systems and to marine habitats constitute important adaptations that result in increased fitness to individuals and population productivity (Gross 1987).

Worldwide, 800,000 dams have been installed in rivers (World Commission on Dams 2000). While dams provide numerous economic and societal benefits, they can have significant effects on the structure and function of river ecosystems (Ward and Stanford 1979) and impact fish populations by effecting habitat and disrupting fish migrations (Freeman et al. 2003). Based on Burke et al. (2009) who developed a framework for assessing environmental effects of dams, the potential effects of dams on river ecosystems can be organized as follows:

- **First-order Impacts**: These are direct effects to physical drivers of fluvial systems that are detectable in the immediate vicinity of a project and are highly predictable in both scope and magnitude. They represent the precursors and causes of secondary ecological responses represented in subordinate effect levels, and therefore represent the "hub" of influence from which other effects will radiate. First-order effects affect: 1) flow regime; 2) water quality; 3) and sediment supply. First-order effects can also act as barriers. Dams placed in migratory corridors can be barriers to migration and result in direct mortality to various life stages undergoing migrations. The barriers may also result in tailwater fisheries developing as a result of a dam blocking migrations, or in salmon spawning below a dam due to its being barrier to passage. For example, winter-run Chinook salmon (*O. tshawytscha*) now spawn below Keswick Dam on the upper Sacramento River due to a lack of access to historical spawning areas higher in the watershed (Moyle 2002).
- **Second-order Impacts**: This category encompasses the habitat processes that result from first-order effects or feedback from third- or fourth-order effects. Second-order effects are indirect (as opposed to first-order effects) and their intensity and propagation varies over spatial and temporal scales. Consequently, they are less predictable, and understanding their probability of occurrence and magnitude requires significant analysis. Secondary effects are highly interdependent and may neither be apparent nor reach a stable/dynamic equilibrium for years or decades after a project is constructed. Second order effects affect: 1) riparian and community succession; 2) armoring of substrate and shorelines downstream of dams (Petts 1979; 1980); 3) ice formation and breakup; 4) floodplain and channel morphology; 5) surface and groundwater flow; 6) sediment erosion and deposition; and 7) nutrient and trophic cycles.
- **Third-order Impacts**: This category encompasses the habitat attributes that are required by salmon or other species that are dependent on fluvial processes to move, erode, and deposit sediment on stream and river beds to form the habitat attributes. These attributes can generally be considered what the species need while they are in freshwater. Third-order effects may be affected by first- or second-order effects, as well as feedback from fourth order effects. Each habitat attribute is potentially interdependent and each species has specific requirements. Habitat attributes can be measured instantaneously and reflect real time habitat conditions. Over multiple generations, the variability in habitat attributes is the foundation of local adaptation and governance of parameters that sustain aquatic species populations. Third-order effects affect: 1) water quality; 2) water quantity; 3) habitat connectivity; and 4) habitat structure.
- **Fourth-order Impacts**: This category encompasses effects to parameters that sustain salmon populations or other species that result from changes to habitat attributes. Whereas habitat attributes reflect instantaneous condition of the available habitat, the population parameters are typically lagged response metrics that reflect changes in long-term sustainability. Using the example of a barrier to passage, the permanent truncation of available spawning habitat or elimination of a specific spawning area would immediately change the spatial structure of affected populations and could reduce life history diversity as well. Fourth order effects affect: 1) abundance; 2) productivity; 3) spatial structure; and 4) diversity.

According to Marmulla (2001), dams can also enhance some riverine fisheries, particularly tailwater fisheries immediately below dams that result from discharge of seston (primarily plankton) from the upstream reservoir. Also, lowered temperatures in the receiving tailwater can curtail or eliminate warmwater river fisheries, and productive tailwater fisheries targeting coldwater fishes can result. For example, fishing effort below dams that are seven times higher than the respective upstream reservoir has been recorded (Marmulla 2001). Nestler et al. (2002) found that when cool, oxygen-rich water is drawn from a reservoir, fish may be attracted to the tailrace area directly below the dam. Indeed, salmon are often attracted to higher flows found in the tailraces of hydroelectric projects (Scruton et al., 2007). Tailrace areas can also be used by fish for spawning (Dauble et al. 1999; Parsley et al. 1993), and flow regulation downstream of dams may stabilize habitats and lead to increased use by spawning and rearing salmon (Ligon et al. 1995).

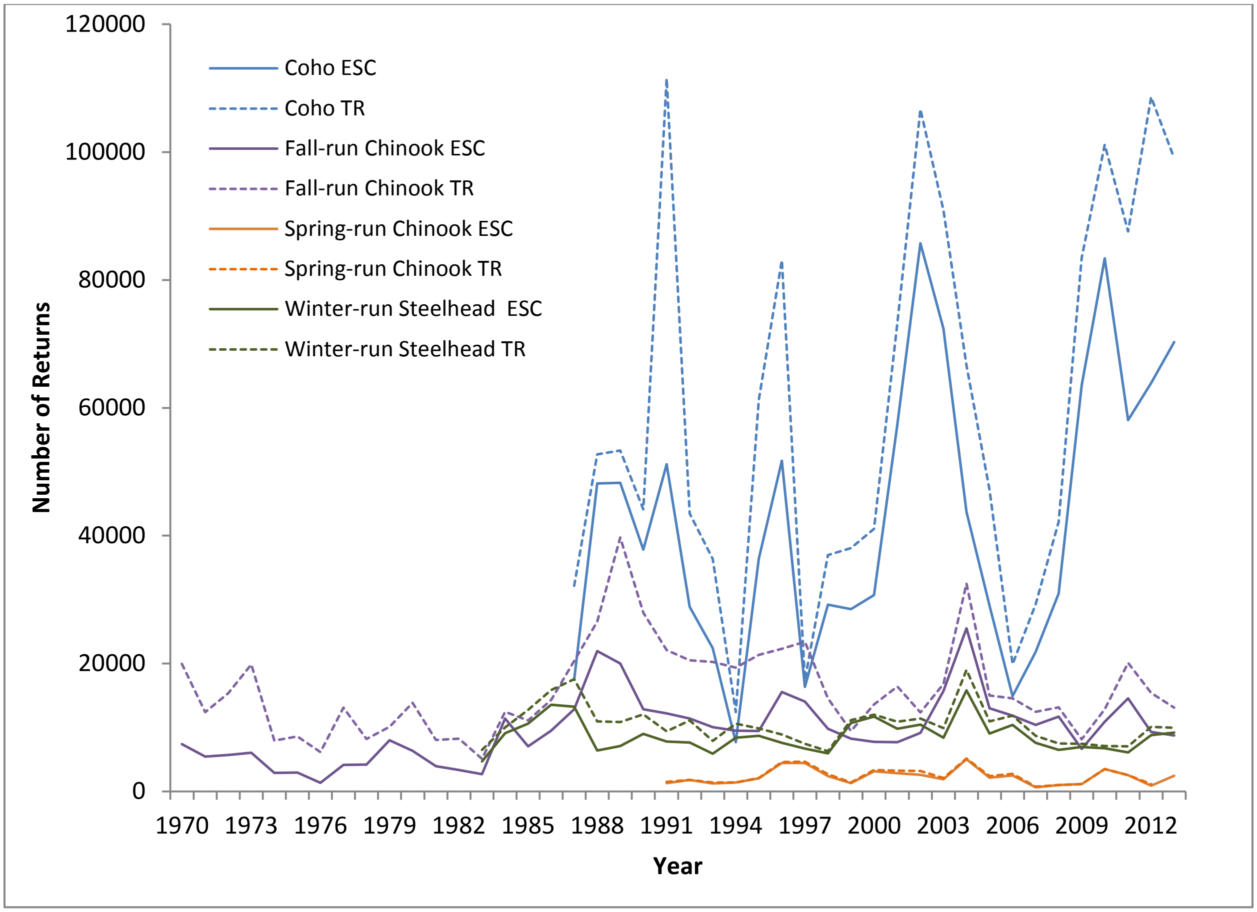
However, as a result of reductions in peak discharges, areas downstream of dams may experience stabilization of shorelines and significant increases in riparian vegetation (Gordon and Meentemeyer 2006). This can have negative effects on channel forming processes, where the shorelines below dams become more resistant to the influences of flow. This resistance to flow can have consequences on channel structure and salmon rearing habitat. For example, in the Trinity River in Northern California, the U.S. Bureau of Reclamation has implemented a program focused on removing riparian berms that had encroached on the river following closure of a water storage dam, lowering floodplains to match the post-dam flow regime, and creating point bars that would promote a dynamic river (Buffington et al. 2014). To be clear, the purpose of the two dams on the Trinity River is to divert 90% of its flow to the Sacramento River basin, which is a very different situation than what is being evaluated in the Chehalis River.

These potential effects on river ecosystems were considered when the analytical approaches used to assess potential effects of water retention structures and climate change on the Chehalis River ecosystem were developed. The companion *Data Gaps Report* identifies the need for a more comprehensive survey of the scientific literature associated with the ecological effects of dams to help inform and guide future studies in the Chehalis basin.

1.8 Recent Trends in Abundance of Chehalis Basin Salmonids

A more detailed discussion of the historical and current status of Key Species in the basin is provided in the companion *ASEP*. Overall trends in salmon population abundance are provided in this report for context. Annual total run and escapement values for salmon species evaluated are shown in Figure 1.2.

Figure 1.2
Recent Spawning Escapement and Total Run Size for Chehalis River Coho Salmon, Fall-run Chinook Salmon, Spring-run Chinook Salmon, and Winter-run Steelhead



Note: ESC = Escapement
TR = Total Run
The date ranges correspond to available data for each species.

2 Analytical Framework

2.1 Introduction

The focus of the analytical framework is habitat: how it is used by species, how it is created and maintained in the Chehalis River system, and how Flood Reduction Alternatives and future climate variability may affect it.

The analytical framework developed for these analyses is depicted in Figure 2.1. Action hypotheses about how Flood Reduction Alternatives and climate change may affect species were developed and translated into potential changes in physical conditions and processes. Drawn from published scientific information, action hypotheses are conceptual models of how actions are expected to change the physical environment. The action hypotheses point to attributes affected by actions and the amount of physical change expected from actions.

Changes in physical processes were then evaluated for their potential effect on aquatic species and guilds through a series of habitat-association and population models. Outputs included changes in habitat, population parameters such as abundance and productivity, and factors limiting the productivity of habitat to support aquatic species. The result of the analytical framework provided insight into how the Chehalis watershed operates as a biological and physical system, and the ecological outcomes that can be expected to occur from various management actions and climate change.

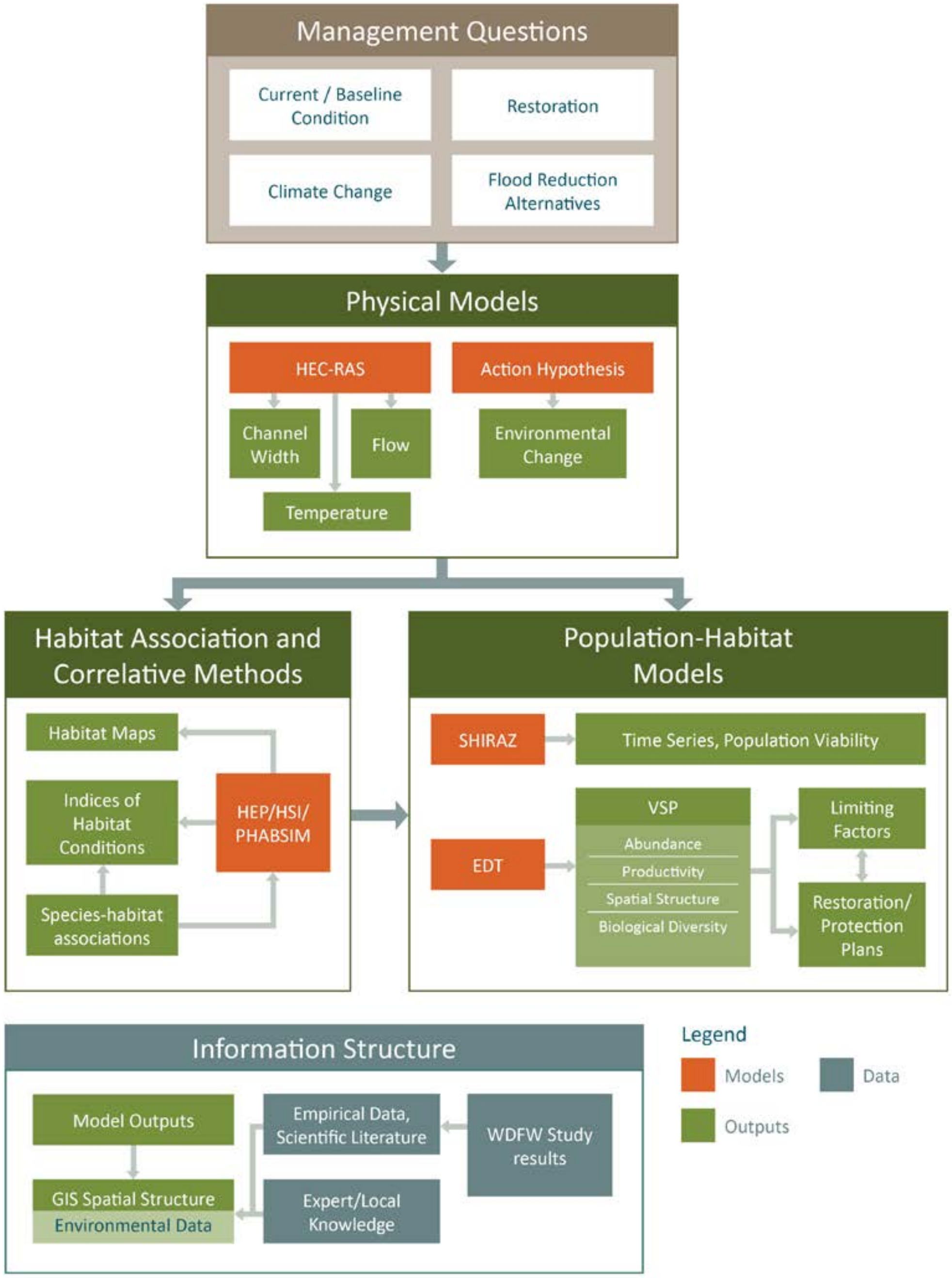
The biological effects of environmental changes were evaluated using the best available information for each Key Species analyzed and selected to represent a guild. This resulted in a variety of models being used to relate habitat characteristics to species distribution, occurrence, or abundance, among three categories:

- Salmon habitat-population models:
  - EDT: Spring- and fall-run Chinook salmon (*O. tshawytscha*), coho salmon, and winter-run steelhead (*O. mykiss*)
  - SHIRAZ: Spring-run Chinook salmon, coho salmon, and winter-run steelhead (mainstem populations only)
- HSIs, which provide the structure needed to model in PHABSIM:
  - Chum salmon (*O. keta*), Pacific lamprey (*Lampetra tridentata*), white sturgeon (*Acipenser transmontanus*), smallmouth bass, largemouth bass, and western toad (*Bufo boreas*)
- Correlative models:
  - Eulachon (*Thaleichthys pacificus*), Olympic mudminnow (*Novumbra hubbsi*), speckled dace (*Rhinichthys osculus*), largescale sucker (*Catostomus macrocheilus*), riffle sculpin (*Cottus gulosus*), reticulate sculpin (*Cottus perplexus*), Dunn's salamander (*Plethodon dunni*), Van Dyke's salamander (*Plethodon vandykei*), coastal tailed frog (*Ascaphus truei*), northern red-legged frog (*Rana aurora*), Oregon spotted frog (*Rana pretiosa*), and North American beaver (*Castor canadensis*)

The essential habitat forming processes involving flow and channel width were analyzed using the River Analysis System (RAS) developed by the Hydrologic Engineering Center (HEC) located in Davis, California, or the HEC-RAS model. HEC-RAS is a widely used hydrological model, and was constructed for the Chehalis system through earlier studies and was updated and further refined through this Project. Temperature data were available through the temperature modeling conducted by Anchor QEA (2012b), a recent Forward Looking Infrared

Radiometer (FLIR) flight, and ongoing water quality monitoring. Changes in channel form, sediment transport, and large woody material supply were supplied by separate analyses (Watershed GeoDynamics and Anchor QEA 2014). The hydrology, geomorphology, and water quality methods and information used in these analyses are described in Section 4.3.

Figure 2.1
ASEP Analytical Framework for the Chehalis River



Notes:
EDT = Ecosystem Diagnosis and Treatment
HEC-RAS = Hydrologic Engineering Center River Analysis System
HEP = Habitat Evaluation Procedure
HSI = Habitat Suitability Index
PHABSIM = Physical Habitat Simulation
WDFW = Washington Department of Fish and Wildlife
VSP = Viable Salmonid Population

2.2 Modeling Biological Effects

The biological effects of the changes captured in the physical models were evaluated using the three categories of biological models identified in Section 2.1. These ranged from models that predict a population's response to changes in habitat conditions, to species-habitat associations models, and finally to simple correlations (e.g., changes in species occupancy or areas of suitable habitat).

Population-habitat models relate habitat conditions to a quantitative measure of species performance such as abundance. To make conclusions, population habitat models require physical data (empirical, or derived from other models or expert knowledge) and biological knowledge of species-habitat relationships, life history, and population structure. Two different population-habitat models were used: EDT and SHIRAZ. The EDT model is a habitat model for salmonids that has been used in many systems throughout the Pacific Northwest including the Chehalis River basin. The Chehalis basin EDT model encompassed the entire Chehalis basin upstream of and including the Wynoochee River. It evaluates habitat at a stream reach scale, and for the Chehalis basin the model consisted of more than 900 reaches. EDT provided a detailed analysis of habitat limitations at various reach scales for each species and sub-population and captured the variability in habitat conditions across the basin. SHIRAZ uses a less detailed habitat depiction than EDT, but stochastically forecasts fish performance. SHIRAZ analyses focused solely on the mainstem Chehalis River below the proposed dam site. The SHIRAZ and EDT models share a common mathematical basis (the dis-aggregated Beverton-Holt stock recruitment relationship) and use various relationships to relate habitat to fish performance. However, SHIRAZ provides estimates of population trends and variability through time. In this way, SHIRAZ outputs provide an indication of the variability in the future of fish populations resulting from habitat changes. This is important information for decision makers because it provides additional information on potential population vulnerabilities resulting from proposed actions.

While the EDT and SHIRAZ models complement each other, they also provide different types of information to help interpret the effects of Flood Reduction Alternatives and climate variability on salmon. While EDT provides a detailed analysis of habitat effects on fish performance, SHIRAZ results include an extra dimension of variability across time and how changes in habitat conditions may affect population dynamics. In addition, studies using the two models were based on different sets of habitat data and were conducted independently for the most part. Therefore, use of both models provided a more comprehensive evaluation of effects of alternatives on salmonids compared to use of a single model. In this manner, areas of agreement and disagreement between the models helped to inform uncertainties and sensitivities in the underlying data and model assumptions.

Species-habitat association models are based on simpler depictions of associations between species and their habitats. The HSI models are more formal representations of habitat associations that compute an index of suitability of modeled conditions for species. These have fewer data requirements than habitat-population models and are available for a number of species. HSI is a flexible approach allowing a wide range of certainty and uncertainty. HSI is not always independent of life history and can be highly quantitative. In these analyses, HSI models were used for key aquatic and terrestrial species with more limited biological information available for use in evaluating action hypotheses.

The final types of models used in these analyses were correlative models, which relate the observed presences of a species to values of environmental variables at sites. The goal of the correlative analysis was to begin development of an ecosystem model for baseline conditions of floodplain inundation that could then be used to estimate changes in inundation associated with flood hazard reduction alternatives. Many Key Species in the Other Fish and Non-fish groups have too little information available on their distribution and life histories to allow for a detailed description of their use of the basin. To address this, indices describing differences in the amount of floodplain area inundated under different peak flows were developed to provide a qualitative measure of the magnitude and direction (positive, negative, or no change) of response for macrohabitat guilds and species associated with those guilds. Quantifying the amount of off-channel habitat currently present under multiple flood scenarios allowed for predictions to be made about changes that could occur with different Flood Reduction Alternatives.

The analytical framework described here focused on multiple species, environments, and habitat controls to provide an overall ecological view of the basin today and estimate the potential effects of flood reduction alternatives and climate change in the future. Development of the analytical framework also resulted in a range of qualitative and quantitative models that are now available for use beyond the present Project.

3 Description of Flood Reduction Alternatives, Dam Operations, and Fish Passage

3.1 Introduction

The Project team identified three dam alternatives that were recommended for further development and consideration:

- Flood reduction only roller compacted concrete (RCC) dam
- Multi-purpose RCC dam
- Multi-purpose rockfill dam

The Flood Reduction Only (FRO) and MPD Alternatives are briefly described in the following sections. A more in-depth description of each alternative can be found in the *Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species: Combined Dam and Fish Passage Alternatives Draft Technical Memorandum* (HDR 2014a). Because the Multi-purpose RCC Dam and rockfill dam are functionally the same with regard to operations, only one of the Multi-purpose Dam (MPD) Structures is referenced here.

3.1.1 SUMMARY OF PROPOSED DAM ALTERNATIVE STRUCTURES

An FRO dam would provide temporary flood storage and not retain a permanent pool upstream of the dam. The current flood reduction dam design has a reservoir storage capacity of 65,000 acre-feet, resulting in an estimated dam height of 232 feet. Under normal flow conditions, the dam would operate where inflow is equal to outflow, releasing water through nine 9-foot-by-12-foot tunnels at the base of the dam. The tunnels would be designed to facilitate the range of expected fish passage flows and velocities. During flood flows, the tunnels would be closed. When the tunnels are closed, flood control releases would occur through a 25-foot-diameter tunnel or over the emergency spillway. The tunnels would be reopened once the stored water has been released and the inflows are equal to outflows once again. Depending on the type of dam construction used, the maximum length of the pool backed up by the FRO Alternative ranges from 6.74 to 6.80 miles during normal operations (excluding the project maximum flood).

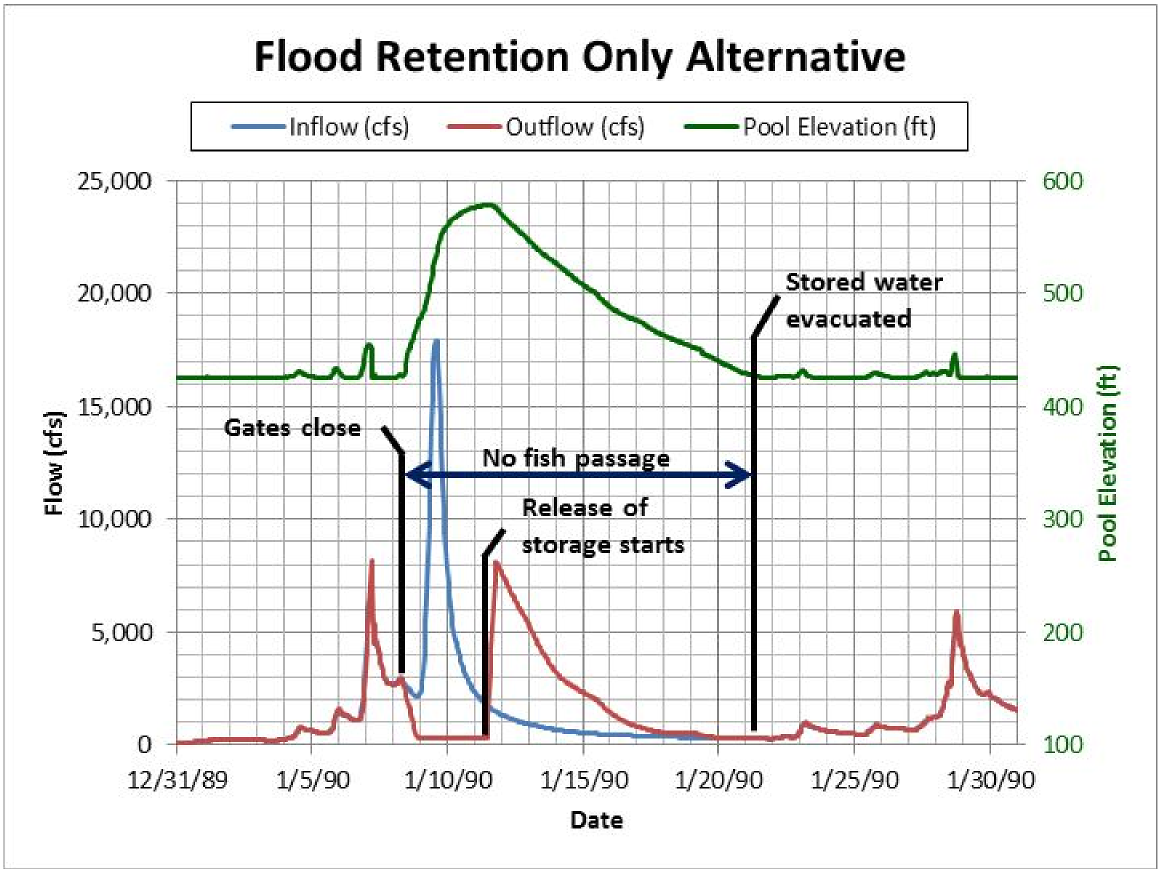
An MPD and reservoir would have a total storage capacity of 130,000 acre-feet. The storage capacity comprises 65,000 acre-feet that can be used for environmental purposes (flow augmentation and water temperature reduction) and 65,000-acre-feet to store flood flow. The estimated MPD height is 292 feet. Elevations of the top conservation and flood reduction pools are, respectively, 628 and 653 feet (spillway crest), which are more than 200 feet above the river channel immediately downstream of the dam. Releases from the permanent pool would be via an outlet at the bottom of the dam, while emergency flood control releases would occur over a 200-foot-wide spillway. Depending on the type of dam construction used, the maximum length of the reservoir backup up by the MPD Alternative ranges from 6.71 to 7.49 miles during normal operations (excluding the project maximum flood).

3.1.2 SUMMARY OF PROPOSED DAM OPERATIONS

The Anchor QEA consulting team developed preliminary operating rules for both the FRO and MPD Alternatives (Anchor QEA 2014a). In general, the FRO dam would be operated as follows:

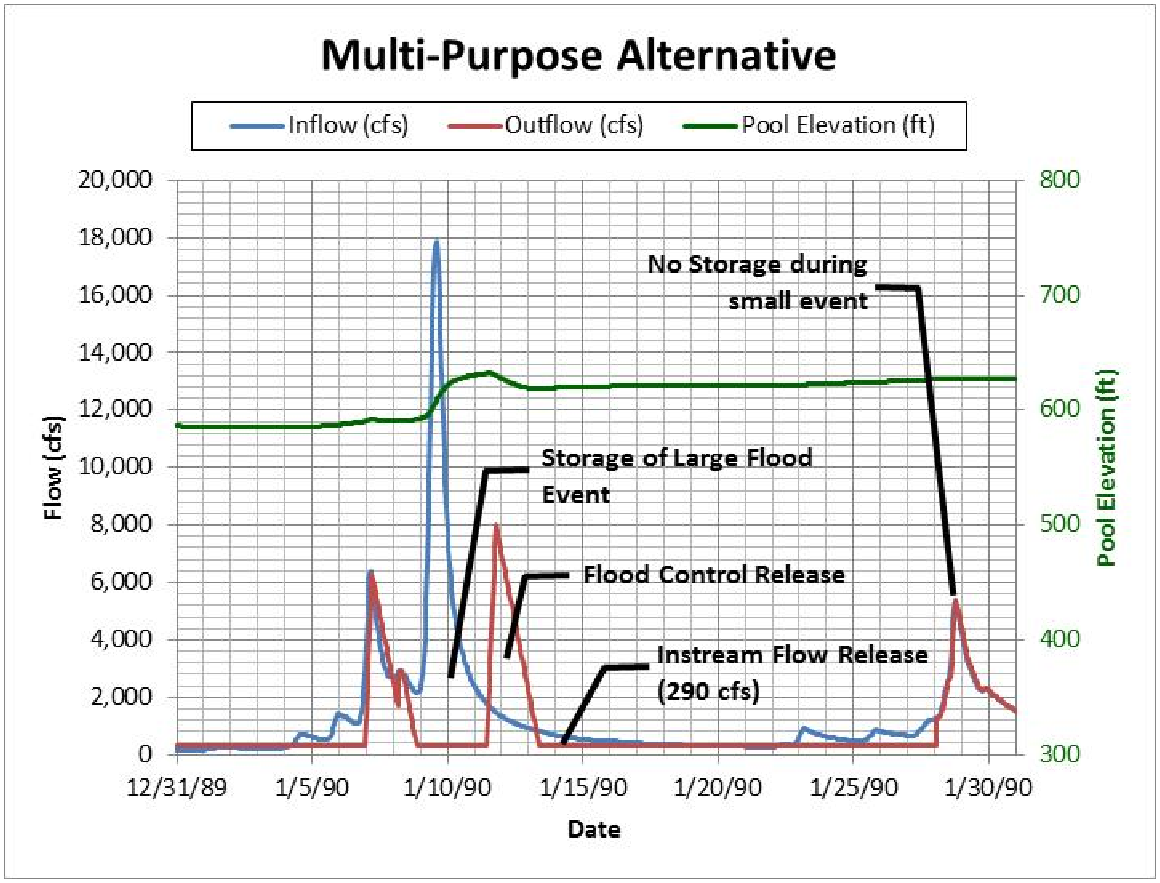
- During normal conditions, the outflow of the reservoir would equal the inflow (natural hydraulic conditions) except during large floods. Reservoir outflow would occur through nine tunnels. Fish passage and sediment control would occur in the tunnels.
- When flows at U.S. Geological Survey (USGS) Gage #12027500 (Chehalis River near Grand Mound) are predicted to be above major flood stage (flows greater 38,800 cfs [1,098 m^3/sec]), the reservoir outflow would be reduced at a rate of 200 cfs per hour until the outflow is equal to 300 cfs (8.5 m^3/sec). Reservoir outflow would be reduced by closing the gates on the tunnels and controlling outflow with the 25-foot-diameter (7.6-m) flood control tunnel.
- Once the flow at the Grand Mound gage has dropped below major flood stage for 48 hours, reservoir outflow would increase by 1,000 cfs (28.3 m^3/sec) per hour, not to exceed a maximum drawdown of 30 feet (9.1 m) per hour. Flood control releases would primarily be released through a 25-foot-diameter (7.6 m) flood control tunnel.
- Once the reservoir is drawn down to stage 426 feet (130 m), inflow would approximately equal outflow (Figure 3.1).
- Fish passage would not occur while the gates on the tunnels are closed or while water is stored behind the reservoir.
- In floods that exceed a 10-year recurrence interval, the reservoir would be drawn down and the water level may be held at an elevation deep enough to collect debris. The reservoir level would be held at this drawn down level for an additional 2 weeks to allow for debris collection if needed.

Figure 3.1
Reservoir Inflow, Outflow, and Stage for the Flood Reduction Only Alternative During the 1990 Flood Event



The MPD Alternative uses similar operation rules as the FRO Alternative to determine when to store water; however, there are slight operational differences for reservoir release depending on the reservoir storage at the start of flood control operations. During the release of impounded water, flow may be retained to replenish the conservation pool. If the reservoir is in the flood reduction pool, releases would be increased by 1,000 cfs per hour up to a maximum of 11,000 cfs (311.5 m^3/sec). During smaller events (inflows greater than or equal to 2,800 cfs), the flow would be allowed to pass through the multi-purpose reservoir assuming the flow at the Grand Mound gage is below flood stage. In addition to providing flood control, the MPD Alternative would be operated to meet in-stream flow requirements ranging in magnitude from 160 to 290 cfs (4.5 to 8.2 m^3/sec) during the course of the year. Reservoir releases may be curtailed by 20% during a drought if the conservation pool is not filled (Figure 3.2).

Figure 3.2
Reservoir Inflow, Outflow, and Stage for the Multi-purpose Dam Alternative During the 1990 Flood Event



Note:
Source: HDR 2014c.

3.2 Methods for Evaluating Fish Passage

3.2.1 FLOOD REDUCTION ONLY DAM ALTERNATIVE

Fish passage was assessed at the FRO Alternative by determining when flood operations were occurring and when the inflow to the reservoir exceeded the high fish passage flow (2,000 cfs [56.6 m^3/sec]). The consulting team developed simulated inflow, outflow, stage, and storage for Water Years (WYs) 1989 to 2012 on an hourly time step for use in this analysis. The consulting team also developed dates when the gates were closed and dates when water was impounded due to flood control operations. The following assumptions were made during the analysis:

- Fish passage does not occur during flood reduction operations (gates closed and/or water stored).
- Fish passage would be provided, at a minimum, up to reservoir inflows of 2,000 cfs (56.6 m^3/sec; the high fish passage design flow).

For this analysis, it was assumed that fish passage would be limited when reservoir inflow exceeded 2,000 cfs (56.6 m^3/sec; HDR 2014b). Preliminary hydraulic modeling of the Flood Reduction Only Alternative by the dam design team indicates velocities of 2 feet (0.6 m) per second could be achieved at inflows of 2,000 cfs (56.6 m^3/sec); however, higher flows were not modeled at this time.

3.2.2 MULTI-PURPOSE DAM ALTERNATIVE

Similar to the FRO scenarios, the consluting team developed hourly simulated stage, storage, inflow, and outflow for the MPD Alternative for WYs 1989 to 2012. The MPD Alternative would retain a permanent pool behind the dam, and reservoir releases would be regulated. As a result, it was necessary to analyze reservoir stage as opposed to flow because a tunnel is not a possibility while maintaining a permanent pool. A stage duration curve was generated from the hourly simulated stage values on an annual basis and also for each migration period for each fish species.

3.3 Fish Passage Considerations for Operation of Flood Retention Only Dam Alternative

3.3.1 ASSESSMENT OF ANNUAL FISH PASSAGE

Results of the fish passage assessment for the FRO Alternative indicated that flood reduction operations would take place in 6 WYs (1990, 1991, 1996, 1997, 2008, and 2009) out of the 24 years included in the analysis. Flood reduction operations ranged in duration from a minimum of half a day to a maximum of 13 days. For the scenario without extra holding time for debris management, fish passage would not be provided for 3.4 days per year (0.9%) due to a complete closure of the tunnels. Additionally, fish passage would be limited on average another 8.9 days per year (2.4%) due to flow in the river exceeding the high fish passage flow of 2,000 cfs (56.6 m^3/sec) through the tunnels. Consecutive high flow events of more than 2,000 cfs (56.6 m^3/sec) ranged in duration from one hour to 4.7 days. Combined, fish passage was estimated to be inhibited an average of 12.3 days (3.4%) per year for flood reduction operations for the FRO Alternative. In comparison, flows greater than 2,000 cfs would be exceeded an average of 9.9 days per year (2.7%) under natural conditions. At that flow rate, fish passage would also be inhibited in the river due to high water velocities. Table 3.1 presents results of the analysis on an annual basis.

Based on an assessment of the extra holding time required for debris management associated with the FRO Alternative, fish passage would not be provided for 5.4 days per year (1.5%) due to complete closure of the tunnels. Additionally, fish passage would be limited on average another 8.9 days per year (2.4%) due to flow in the river exceeding the high fish passage flow of 2,000 cfs (56.6 m^3/sec) through the tunnels. Consecutive high flow events of more than 2,000 cfs (56.6 m^3/sec) ranged in duration from one hour to 4.7 days. In total, fish passage was estimated to be inhibited an average of 14.3 days (3.9%) per year for flood reduction and debris management activities associated with the FRO Alternative. In comparison, flows greater than 2,000 cfs would be exceeded an average of 9.9 days per year (2.7%) under natural conditions. At that flow rate, fish passage would also be inhibited in the river due to high water velocities. Table 3.2 presents results of the analysis on an annual basis.

3.3.2 ASSESSMENT OF FISH PASSAGE BY SPECIES

In general, fish passage would be most effected during the winter months (November to February), when flood reduction operations are more likely to occur, and flows are more likely to be above the high fish passage design flow (Tables 3.3 and 3.4). January had the highest average total inhibited passage of 3.5 days without the extra holding time for debris management and 4.5 days with the extra holding time. December had the second most, with an average of 3.2 days of total inhibited passage for the scenario without extra holding time and 3.8 days with the extra holding time. Fish passage is not expected to be impeded by the FRO Alternative in May through September.

Upstream fish migration timing was overlaid on the average monthly inhibited passage duration (Figures 3.3 and 3.4). All species shown are present during months with expected limited fish passage. Winter-run steelhead, coastal cutthroat trout (*O. clarki clarki*), and coho salmon are the most likely to be effected by the FRO Alternative.

Table 3.1
Total Duration Where Limited Fish Passage Occurs by Water Year, Water Years 1989 to 2012
(Without Extra Holding Time for Debris Management)

WATER YEAR	FLOOD REDUCTION OPERATIONS			HIGH FLOW (ABOVE 2,000 CFS)			TOTAL		
	HOURS	DAYS	%	HOURS	DAYS	%	HOURS	DAYS	%
1989	0	0.0	0.0%	86	3.6	1.0%	86	3.6	1.0%
1990	506	21.1	5.8%	138	5.8	1.6%	644	26.8	7.4%
1991	499	20.8	5.7%	129	5.4	1.5%	628	26.2	7.2%
1992	0	0.0	0.0%	142	5.9	1.6%	142	5.9	1.6%
1993	0	0.0	0.0%	22	0.9	0.3%	22	0.9	0.3%
1994	0	0.0	0.0%	71	3.0	0.8%	71	3.0	0.8%
1995	0	0.0	0.0%	327	13.6	3.7%	327	13.6	3.7%
1996	306	12.8	3.5%	341	14.2	3.9%	647	27.0	7.4%
1997	14	0.6	0.2%	263	11.0	3.0%	277	11.5	3.2%
1998	0	0.0	0.0%	190	7.9	2.2%	190	7.9	2.2%
1999	0	0.0	0.0%	664	27.7	7.6%	664	27.7	7.6%
2000	0	0.0	0.0%	264	11.0	3.0%	264	11.0	3.0%
2001	0	0.0	0.0%	0	0.0	0.0%	0	0.0	0.0%
2002	0	0.0	0.0%	414	17.3	4.7%	414	17.3	4.7%
2003	0	0.0	0.0%	209	8.7	2.4%	209	8.7	2.4%
2004	0	0.0	0.0%	139	5.8	1.6%	139	5.8	1.6%
2005	0	0.0	0.0%	112	4.7	1.3%	112	4.7	1.3%
2006	0	0.0	0.0%	469	19.5	5.4%	469	19.5	5.4%
2007	0	0.0	0.0%	440	18.3	5.0%	440	18.3	5.0%
2008	303	12.6	3.4%	137	5.7	1.6%	440	18.3	5.0%
2009	313	13.0	3.6%	65	2.7	0.7%	378	15.8	4.3%
2010	0	0.0	0.0%	134	5.6	1.5%	134	5.6	1.5%
2011	0	0.0	0.0%	183	7.6	2.1%	183	7.6	2.1%
2012	0	0.0	0.0%	232	9.7	2.6%	232	9.7	2.6%
Total	1.941	80.9	0.9%	5.171	215.5	2.5%	7.112	296.3	3.4%
Average	80.9	3.4	0.9%	215.5	9.0	2.5%	296.3	12.3	3.4%

Table 3.2
Total Duration Where Limited Fish Passage Occurs by Water Year, Water Years 1989 to 2012
(With Extra Holding Time for Debris Management)

WATER YEAR	FLOOD REDUCTION OPERATIONS			HIGH FLOW (ABOVE 2,000 CFS)			TOTAL		
	HOURS	DAYS	%	HOURS	DAYS	%	HOURS	DAYS	%
1989	0	0.0	0.0%	86	3.6	1.0%	86	3.6	1.0%
1990	733	30.5	8.4%	126	5.3	1.4%	859	35.8	9.8%
1991	535	22.3	6.1%	122	5.1	1.4%	657	27.4	7.5%
1992	0	0.0	0.0%	142	5.9	1.6%	142	5.9	1.6%
1993	0	0.0	0.0%	22	0.9	0.3%	22	0.9	0.3%
1994	0	0.0	0.0%	71	3.0	0.8%	71	3.0	0.8%
1995	0	0.0	0.0%	327	13.6	3.7%	327	13.6	3.7%
1996	627	26.1	7.1%	341	14.2	3.9%	968	40.3	11.0%
1997	14	0.6	0.2%	263	11.0	3.0%	277	11.5	3.2%
1998	0	0.0	0.0%	190	7.9	2.2%	190	7.9	2.2%
1999	0	0.0	0.0%	664	27.7	7.6%	664	27.7	7.6%
2000	0	0.0	0.0%	264	11.0	3.0%	264	11.0	3.0%
2001	0	0.0	0.0%	0	0.0	0.0%	0	0.0	0.0%
2002	0	0.0	0.0%	414	17.3	4.7%	414	17.3	4.7%
2003	0	0.0	0.0%	209	8.7	2.4%	209	8.7	2.4%
2004	0	0.0	0.0%	139	5.8	1.6%	139	5.8	1.6%
2005	0	0.0	0.0%	112	4.7	1.3%	112	4.7	1.3%
2006	0	0.0	0.0%	469	19.5	5.4%	469	19.5	5.4%
2007	0	0.0	0.0%	440	18.3	5.0%	440	18.3	5.0%
2008	586	24.4	6.7%	109	4.5	1.2%	695	29.0	7.9%
2009	619	25.8	7.1%	65	2.7	0.7%	684	28.5	7.8%
2010	0	0.0	0.0%	134	5.6	1.5%	134	5.6	1.5%
2011	0	0.0	0.0%	183	7.6	2.1%	183	7.6	2.1%
2012	0	0.0	0.0%	232	9.7	2.6%	232	9.7	2.6%
Total	3114	129.8	1.5%	5124	213.5	2.4%	8238	343.3	3.9%
Average	129.8	5.4	1.5%	213.5	8.9	2.4%	343.3	14.3	3.9%

Table 3.3
Mean Monthly Duration of Limited Fish Passage, Water Years 1989 to 2012
(Without Extra Holding Time for Debris Management)

MONTH	MEAN MONTHLY LIMITED PASSAGE DURATION (DAYS)		
	FLOOD REDUCTION OPERATIONS	HIGH FLOW (ABOVE 2,000 CFS)	TOTAL
January	1.0	2.5	3.5
February	0.9	1.0	1.9
March	0.0	0.8	0.8
April	0.5	0.1	0.6
May	0.0	0.0	0.0
June	0.0	0.0	0.0
July	0.0	0.0	0.0
August	0.0	0.0	0.0
September	0.0	0.0	0.0
October	0.0	0.2	0.2
November	0.3	1.7	2.1
December	0.6	2.6	3.2
Total	3.4	9.0	12.3

Table 3.4
Mean Monthly Duration of Limited Fish Passage, Water Years 1989 to 2012
(With Extra Holding Time for Debris Management)

MONTH	MEAN MONTHLY LIMITED PASSAGE DURATION (DAYS)		
	FLOOD REDUCTION OPERATIONS	HIGH FLOW (ABOVE 2,000 CFS)	TOTAL
January	1.9	2.5	4.4
February	1.4	1.0	2.4
March	0.1	0.8	0.9
April	0.5	0.1	0.6
May	0.0	0.0	0.0
June	0.0	0.0	0.0
July	0.0	0.0	0.0
August	0.0	0.0	0.0
September	0.0	0.0	0.0
October	0.0	0.2	0.2

MONTH	MEAN MONTHLY LIMITED PASSAGE DURATION (DAYS)		
	FLOOD REDUCTION OPERATIONS	HIGH FLOW (ABOVE 2,000 CFS)	TOTAL
November	0.3	1.7	2.1
December	1.2	2.5	3.7
Total	5.4	8.9	14.3

Figure 3.3
Average Monthly Duration of Limited Fish Passage with Upstream Migration Periodicity for Flood Retention Only Alternative, Water Years 1989 to 2012

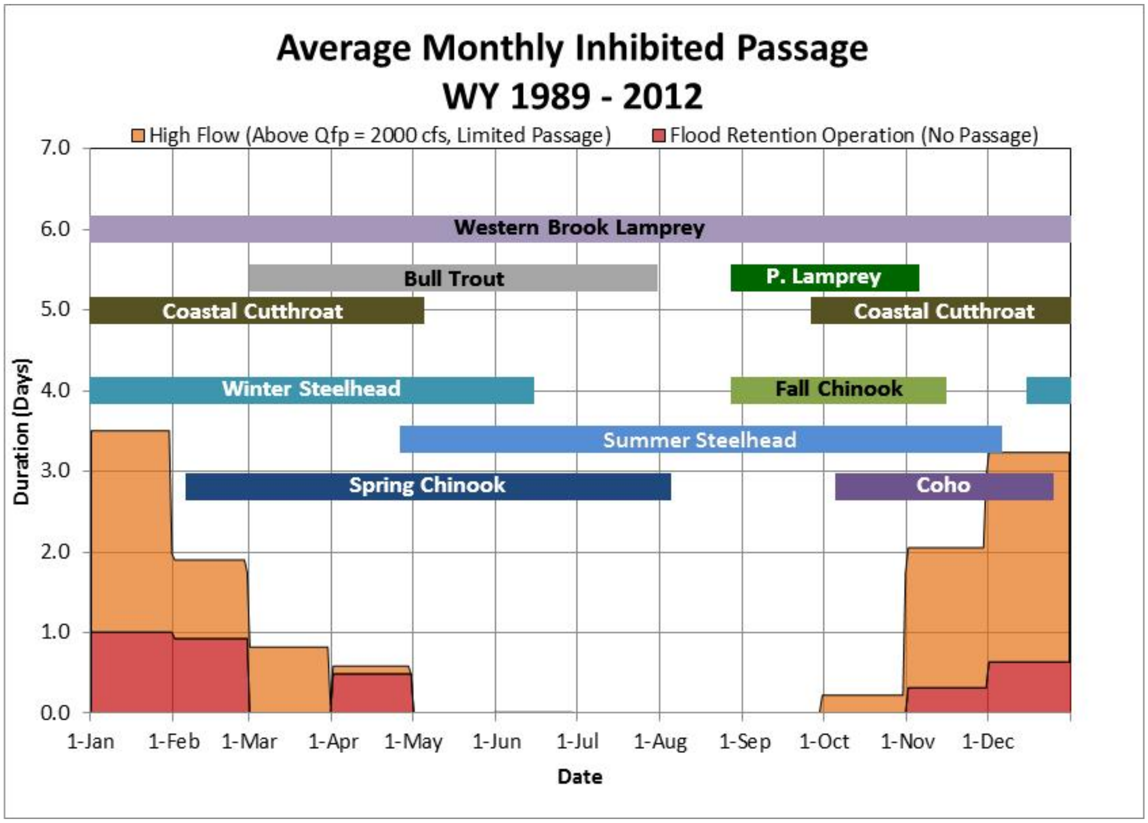
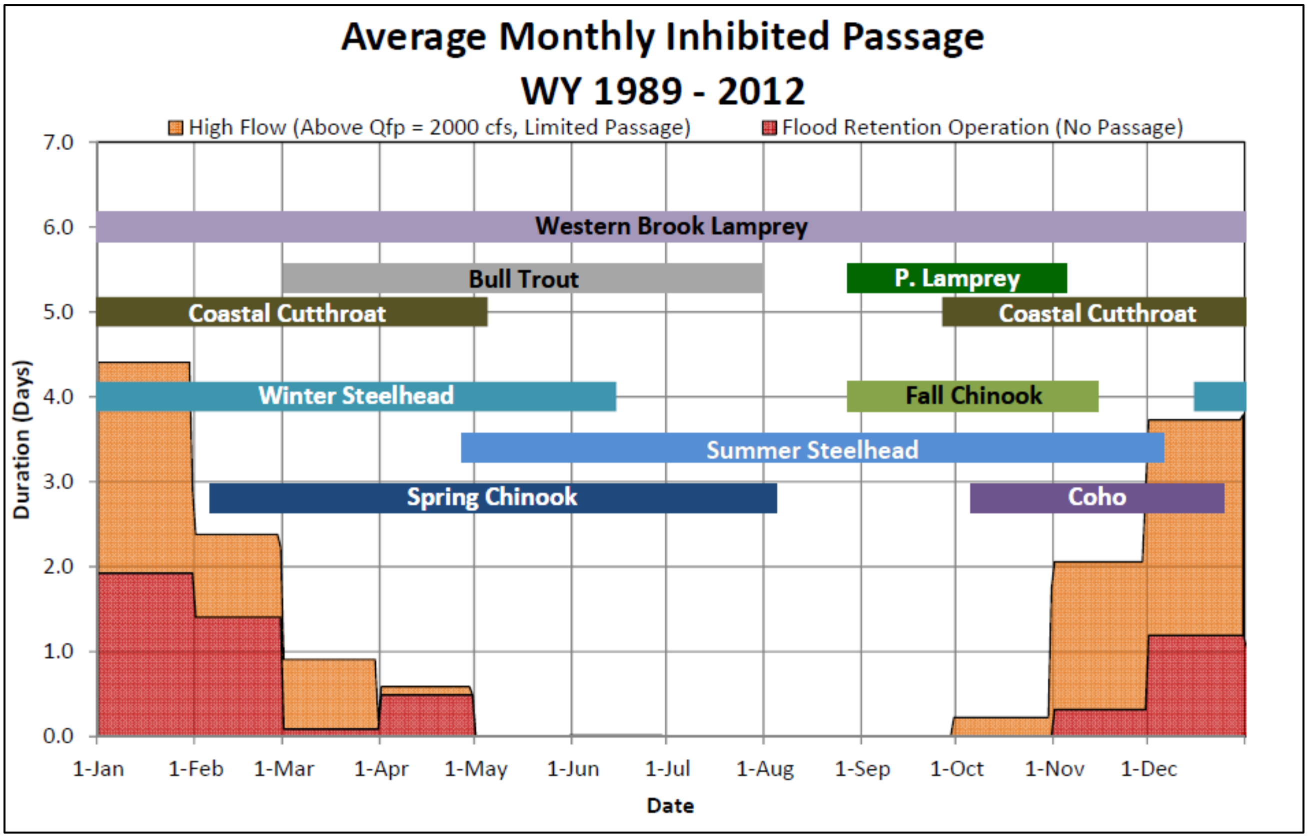


Figure 3.4
Average Monthly Duration of Limited Fish Passage with Upstream Migration Periodicity for Flood Retention Only Alternative with Extra Holding Time for Debris, Water Years 1989 to 2012



3.4 Fish Passage Considerations for Operation of Multi-purpose Dam Alternative

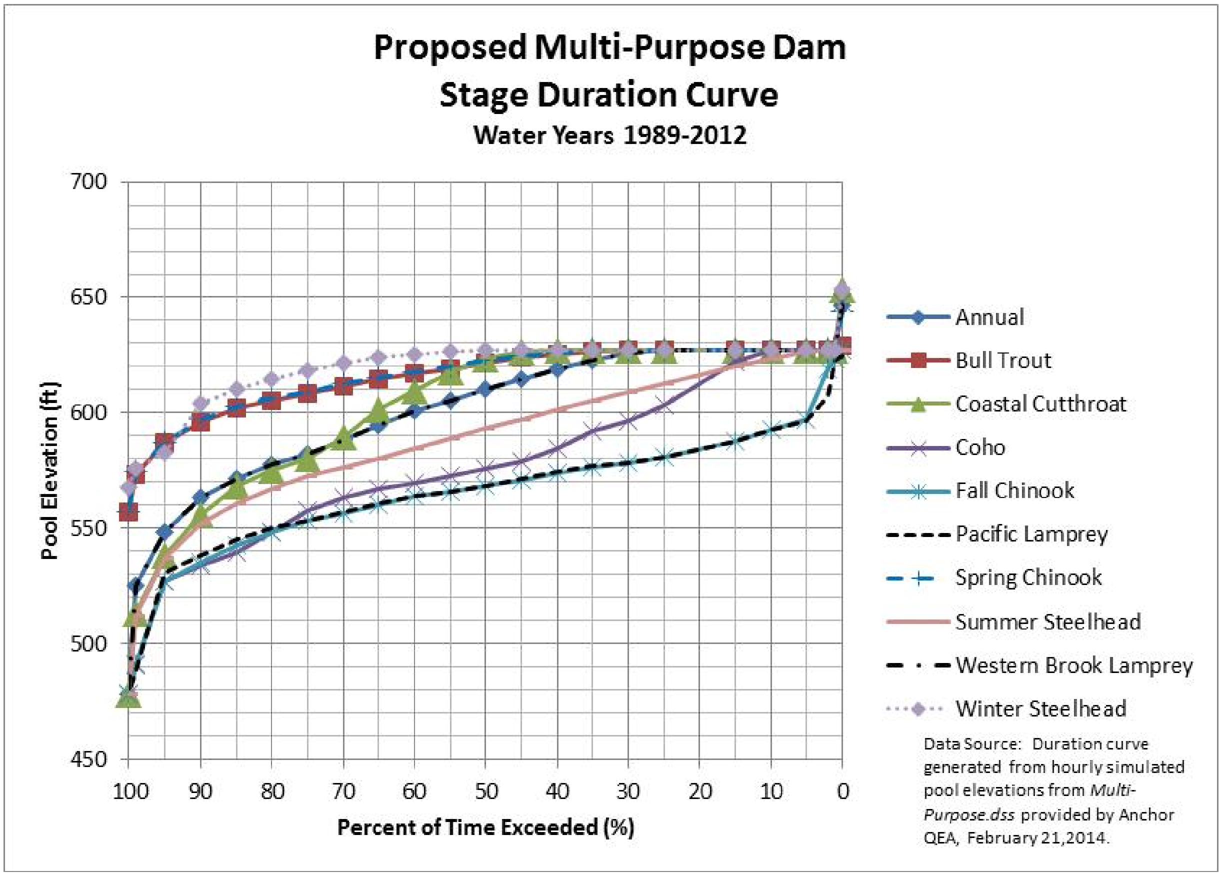
Simulated reservoir stage values for the MPD Alternative range from a minimum of 478.3 feet (145.8 m) to a maximum of 671.5 feet (204.7 m; Table 3.5). The median simulated stage is 610 feet (186 m). The flood control pool is accessed less than 1% of the time because it is above the corresponding water conservation pool elevation of 628 feet (191.4).

Stage duration curves were created for each period of migration for each fish species (Figure 3.5). Reservoir levels were lowest during Pacific lamprey and fall-run Chinook migration periods and highest during bull trout, winter-run steelhead, and spring-run Chinook salmon migration periods. Median stages ranged from about 569 feet (173 m; Pacific lamprey) to 627 feet (191 m; multiple species). In order to encompass the range of expected medians for all species, at a minimum fish passage would have to be provided over a range of 58 feet (17.7 m), which is much larger than the assumed 30-foot (9.1 m) vertical window that could be provided by a conventional fish ladder or similar facility.

Table 3.5
Annual Stage Duration Anticipated for Multi-purpose Flood Retention Dam Alternative Water Years 1989 to 2012

EXCEEDANCE (%)	STAGE (FEET)
0	671.5
0.1	646.5
1	627.1
5	627.0
10	627.0
20	627.0
30	626.0
40	619.1
50	610.0
60	600.8
70	588.4
80	577.7
90	563.3
100	478.3

Figure 3.5
Upstream Migration Stage-duration Curves for Multi-purpose Alternative, WYs 1989 to 2012



Note:
Source: HDR 2014c.

3.5 Summary

Analyses of fish passage were performed for the FRO Alternative using two scenarios: the first assumed the reservoir could be emptied fairly quickly without special consideration for debris management and the second incorporated an additional two-week period to hold the reservoir pool at an elevation that allowed for the collection and handling of debris that could accumulate in the reservoir during large floods. The second scenario was based on the prediction that floods with over a 10-year recurrence interval may need the additional time for debris management. The first scenario was projected to have an average of 3.4 days per year of no passage due to flood reduction operations, and 8.9 days of inhibited passage associated with high flows (more than 2,000 cfs [56.6 m^3/sec]), for an annual average of 12.3 days of limited or no passage per year (HDR 2014a). The second scenario incorporating the extra time for debris management would have an average of 5.4 days per year of no passage due to debris management activities and 8.9 days of inhibited passage associated with high flows, for an annual average of 14.3 days of limited or no passage each year. In comparison, high flows (more than 2,000 cfs [56.6 m^3/sec]) under existing (i.e., no dam or natural river) conditions would be exceeded an average of 9.9 days per year (2.7%). At that flow rate, fish passage in the river would be inhibited due to high water velocities. Most no-passage events would occur from November through February. Analyses of water retention alternatives using EDT and SHIRAZ incorporated estimated passage success (facility collection efficiency and fish passage survival) into model studies on an annual basis. The analyses did not evaluate the effects that the timing of flood reduction events within a year, their duration and magnitude, and debris management activities may have on salmon populations. The need for these studies in future phases of the Project are addressed in the companion *Data Gaps Report*.

The regulation of reservoir releases associated with the MPD Alternative would present challenges for providing fish passage. More than 99% of the time, the reservoir is within the conservation pool; however, the simulated reservoir stages in the conservation pool vary from 478.3 to 628 feet (145.8 to 191 m), a difference of about 150 feet (45.7 m). Additionally, the median stage associated with migration window for each species varies from 569 to 627 feet (173 to 191 m), a difference of 58 feet (17.7 m).

4 Analysis of Flood Retention Alternatives on Aquatic Resources

4.1 Introduction

Two types of flood reduction actions were assessed: water retention alternatives located in the upper Chehalis basin and small flood protection projects located throughout the basin.

4.2 Water Retention Alternatives Modeled

Two water retention alternatives were evaluated: an FRO Alternative and an MPD Alternative. The primary differences between the two alternatives from an aquatic resources standpoint are how often each alternative floods stream habitat during flood events, whether fish have an opportunity to rear in a reservoir, whether flow can be released from the dam for environmental benefits downstream, the degree to which sediment and wood pass through each alternative to affect geomorphic processes in the channel and floodplain downstream from the dam, and the fish passage facilities required for each alternative.

The FRO Alternative stores water for short periods of time. The length of the reservoir would vary with the flood event, and would be approximately 7 miles (11 km) in length at maximum capacity. Between storage events, the reservoir would be evacuated and the river returned to its channel and normal flows. However, the channel would be altered by the project. Upstream of the dam, it would no longer have the same riparian buffer, and shading and food inputs from the riparian zone to the river would be greatly diminished within the footprint of the reservoir. Also, the in-stream channel would no longer be a typical pool-riffle-run configuration. It would be changed to one that fluctuated irregularly between two different states: being sedimented immediately after a flood reduction event, and then after exposure to flow, it would adjust to a more typical channel structure where sediment deposited in the channel would be mobilized and transported downstream. Water temperatures downstream of the dam would reflect ambient temperatures with the potential for increases over current conditions due to a lack of riparian buffers in the footprint of the dam.

In contrast, the MPD Alternative would also inundate approximately 7 miles (11 km) of mainstem and tributary aquatic habitat, but for much of the year. From spring through late summer, when sufficient precipitation allows for it, water stored in the conservation pool (65,000 acre-feet; 80,176,320 m^3) would be released for environmental purposes to increase river flow and cool the mainstem during the low flow season. From a water quality standpoint, assuming there is sufficient runoff in a given year to allow water to be stored for conservation purposes and the reservoir stratifies, colder water could be released from the reservoir through various outlets. During flood events, an additional 65,000 acre-feet (80,176,320 m^3) of storage would be available for storage in addition to the conservation pool volume.

Analyses of how the water retention alternatives affect aquatic species incorporated the operations developed for each water retention alternative. However, it should be pointed out that these operations, especially for the MPD Alternative, could potentially be refined further to provide additional benefits to aquatic species and address potential effects associated with the climate change scenarios that were evaluated.

Two broad areas of study with respect to the water retention alternatives were addressed: changes in habitat in the reservoir footprint area, and changes in physical processes and likely effects on habitat in and along the mainstem Chehalis River downstream from the dam location.

4.2.1 DAM AND RESERVOIR FOOTPRINT

For salmonids evaluated using EDT under the MPD Alternative, the habitat function in the model was set to 100% pool habitat. To model the effect of habitat loss associated with the FRO reservoir on salmonids, the habitat function of the reservoir in EDT was set to large cobble, which results in minimal rearing or spawning occurring but allows fish passage through the area. As discussed in Section 4.5.1, three assumptions about habitat condition associated with the FRO Dam Alternative were modeled. To estimate any effects of reduced fish passage efficiency with dam alternatives, the proposed operating scenarios for both dam alternatives were reviewed and combined with information from the *Fish Passage Briefing Report* (HDR 2014b) to arrive at estimated passage efficiencies (see Appendix B, Table B-5).

4.2.2 DOWNSTREAM FROM THE DAM

Information needed on changes in physical processes in the mainstem Chehalis River downstream from the dam was grouped into four categories: the hydrologic regime, water temperature, channel structure and substrate composition, and floodplain inundation. The Anchor QEA consulting team reviewed existing databases, collected additional information, or conducted additional analyses that quantified how each of the physical processes were anticipated to change under the two dam alternatives. The information was incorporated into the analytical framework and used to assess the effects of changes in physical processes on habitats important to Key Species and guilds. Because of its importance overall, water temperature information is described in the introduction (Section 1.5.2.5) of the companion *ASEP*. The other physical process categories are described in the following sections along with recent information collected on the movement of tagged juvenile salmon in the basin. Due to a lack of information, oxygen levels in the Chehalis River downstream from water retention alternatives were assumed to be unchanged from current conditions.

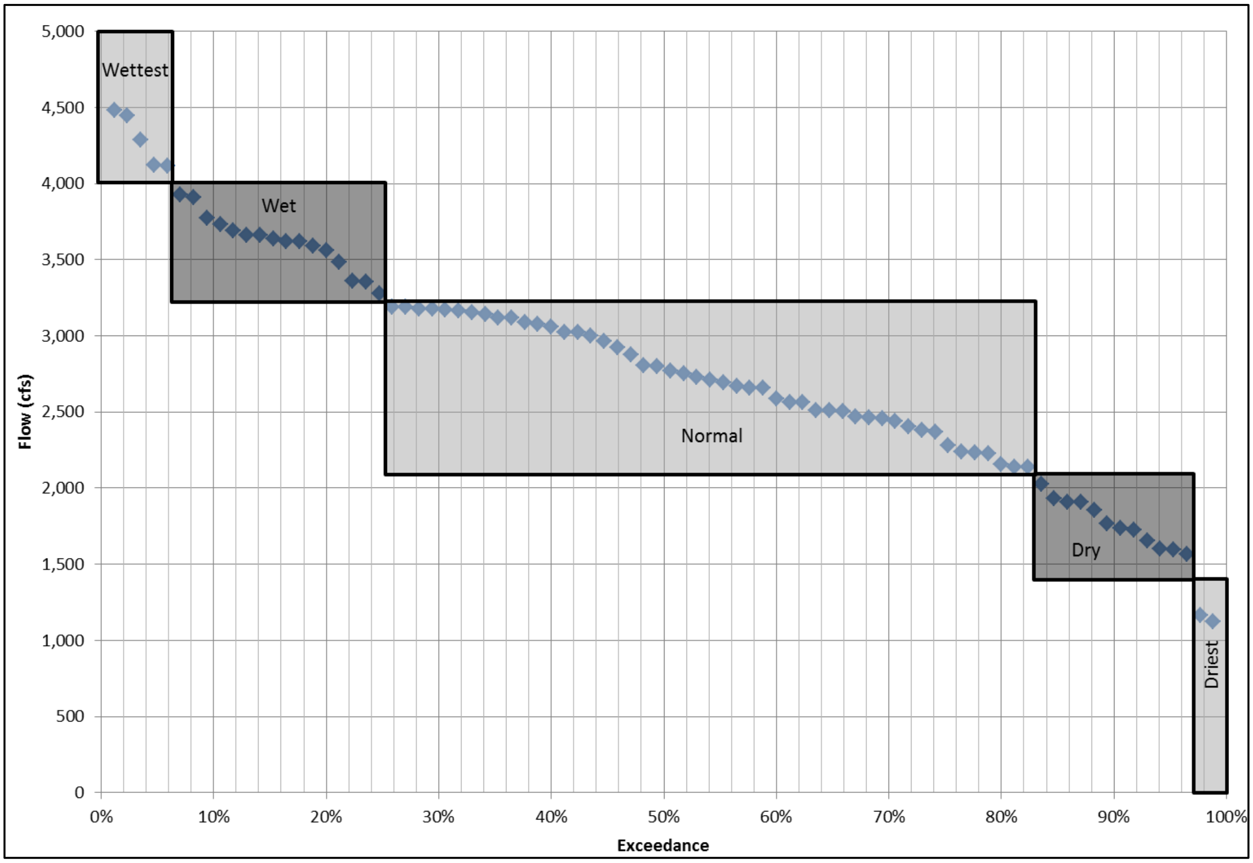
4.3 Physical Processes Modeled and Preliminary Results of Juvenile Salmon Movement Studies

4.3.1 CHEHALIS HYDROLOGY: REPRESENTATIVE YEARS AND PROBABILITIES

The amount of habitat available to aquatic species depends in part on river discharge. Estimates of the amount of habitat available in the Chehalis River were developed from recent studies (Normandeau 2012a). Because water quantity varies from year to year and modeling every year would be cost and time-prohibitive, individual WYs representative of different ranges of WYs were analyzed. Daily flow data were reviewed at USGS gage #12027500 Chehalis River at Grand Mound (Grand Mound gage). This gage was chosen because it has the longest period of record on the mainstem Chehalis River (84 years; 1929 to 2012), which produces a basin-level representation of hydrologic conditions useful for modeling.

Mean annual flows from daily data were reviewed and each WY was categorized into one of five categories: driest, dry, normal, wet, and wettest. Category ranges were chosen by estimating natural breaks in the mean annual flow exceedance chart shown in Figure 4.1.

Figure 4.1
Mean Annual Flow Exceedance: Grand Mound Gage



Based on the results observed in Figure 4.1, probabilities were developed that approximate the chance of a specific WY category occurring (Table 4.1).

Table 4.1
Water Year Category Exceedance and Probability

CATEGORY	EXCEEDANCE BREAKPOINT	PROBABILITY
Driest	100%	2%
Dry	97.6%	14%
Normal	83.5%	59%
Wet	24.7%	19%
Wettest	5.8%	6%

Representative WYs were then chosen for each category based on the following and used for analyses (Table 4.2):

- WYs chosen were between years 1989 and 2012, and preferably between years 2001 and 2012, because sub-daily flow data were available at USGS gages since 1989 and temperature data were available from various sources since 2001.

- WYs chosen were representative of low-flow summer conditions and high-flow winter conditions. In the Chehalis Basin, highest flows occur from December to February, and lowest flows from July to September.

Table 4.2
Representative Water Years

CATEGORY	WATER YEAR
Driest	2001
Dry	2009
Normal	2008
Wet	2011
Wettest	1997

WY 2001 was chosen to represent the driest condition because it had relatively normal summer flows (ranked 32nd of 84 years) but the second driest winter on record (ranked 83rd). WY 2009 represented dry conditions. It was on the edge of the dry/normal boundary on an annual basis (ranked 70th), and both winter and summer months were also near the normal/dry boundary (summer ranked 57th and winter ranked 69th). WY 2008 represented normal conditions. WY 2008 was on the wetter side of normal for the summer and winter months (summer ranked 20th and winter ranked 28th), but overall, this was a median year (ranked 43rd). Note that WY 2008 included the large flood of December 2007. However, that flood was of short duration, which diminished its influence on the overall ranking. WY 2011 had a wet summer (ranked 16th) and an average winter (ranked 41st). WY 1997 represented the wettest WY condition and had the second wettest summer and 6th wettest winter on record. While the WYs chosen did not exactly fit each specific category of WY throughout all days or all months, they provided a general representation of the hydrology for the various categories and enough variation to assess a range of conditions. The five WYs selected were then input into the Chehalis HEC-RAS model to calculate average depth, channel width, and velocity at numerous cross sections in the model that extended throughout the longitudinal gradient of the mainstem Chehalis River.

To characterize changes in habitat associated with water retention alternatives, HEC-RAS runs were conducted using the 24 years of flow record where daily average flows (based on sub-daily flow data) were available (WYs 1989 to 2012) on the operation scenario for each alternative. At the upper extent of the HEC-RAS model (at the dam location), flows were set to a minimum of 150 cfs (4.4 m^3/sec) to allow the HEC-RAS model to run in its normal mode (an unsteady state). For flows below this threshold, the HEC-RAS model had to be run in another mode (steady state) because the model was calibrated to peak flow events and proved to be unstable under low flow conditions when run in the normal mode.

All EDT analysis except that associated with climate change (see Section 5.3.1.1.2) was based on the normal WY condition. Outputs from the HEC-RAS model (monthly averages) were converted into GIS layers of inundation and used to estimate the amount of habitat (average channel width) for each river reach (i.e., each diagnostic unit) in EDT for the mainstem Chehalis River (Appendix B). For all EDT model studies, initially data from Normandeau (2012a) was input into the model. These data were then replaced with data collected during the WDFW riverscape survey that was conducted in 2013, and where habitat types were provided as percent of a river reach. Habitat quantity was computed as follows: reach length X average channel width (as a function of flow) X percent habitat type. Habitat composition was assumed to be constant with flow, but channel width varied with flow.

HEC-RAS model outputs of peak flow events (2-, 10-, 20-, 100-, and 500-year floods) were also used to inform the effects changes in river hydrology may have on habitats used by Other Fish and Non-fish Species, such as off-channel and backwater habitats. Because operations under flood events for both water retention alternatives were assumed to be similar (i.e., outflows would increase to 10,000 cfs [283 m^3/sec]), the HEC-RAS model runs for these studies simply represented the with-dam, and without-dam, flow conditions.

4.3.1.1 CHANNEL STRUCTURE AND SUBSTRATE

Potential changes in geomorphic parameters associated with water retention alternatives used in the analyses were based on Watershed GeoDynamics and Anchor QEA (2014). The geomorphic parameters selected for the analyses included bedload transport and substrate, large woody material supply, channel migration, and sediment retention and debris loading in the water retention reservoir areas.

Watershed GeoDynamics and Anchor QEA (2014) reported that one feature of the Chehalis River that is not typical of Pacific Northwest rivers is the extremely low gradient (0.03%) reach between RM 61.7 and 75.5 (99.3 and 121.5 RKm) near the city of Chehalis, Washington. It is also noted that the 2007 flood had a profound effect on the Chehalis River system that will persist for decades, particularly in upstream reaches. The combination of the large peak flow and inputs of wood and sediment in the headwaters of the Chehalis and South Fork Chehalis Basins during the 2007 flood resulted in deposition of channel-filling gravels upstream of RM 104, large log jams that caused a channel avulsion near RM 104.5 (168.2 RKm), and overbank wood and fine sediment deposits up to 6 feet deep in unconfined reaches. These log jams were subsequently removed and that source of wood for channel-forming processes eliminated from the system. The gravel deposits upstream of RM 104.5 (168.2 RKm) resulted in substantial fining of the substrate and currently provides spawning habitat for fish. Through time, these deposits will be re-worked and transported downstream until the river reaches a dynamic equilibrium with the bed material. This will result in coarser cobble substrate in much of the upper watershed similar to conditions noted prior to the 2007 flood. These changes to the upper Chehalis River that occurred since the EDT model was developed for the Chehalis in 2003 required that the model be updated to account for the changes.

Overall, construction and operation of either water retention alternative would alter downstream geomorphologic processes by altering peak flows, bedload supply and transport, and large woody material supply and transport (Watershed GeoDynamics and Anchor QEA 2014). Key findings from the Watershed GeoDynamics and Anchor QEA (2014) report for each of the geomorphic parameters considered during these analyses are summarized in the following paragraphs.

4.3.1.1.1 Bedload Transport and Substrate

Under the FRO Alternative, relative changes to bedload supply and transport would be minimal and would remain in the same geomorphic state at most of the modeled transects. The area near RM 104.49 (168.2 RKm) will continue to be a depositional reach. The area near RM 85.05 (153 RKm) may undergo erosion or coarsening of the bed. Because all upstream bedload would be trapped in the MPD reservoir, it is expected that coarsening of the bed would occur in most areas of the river upstream of RM 70 (112.7 RKm) under the MPD Alternative.

4.3.1.1.2 Large Woody Material

Changes to large woody material input and transport will occur under either the FRO or MPD Alternatives. During high flow events, woody material coming from upstream would be intercepted by either reservoir because the impoundment would be filling or full during peak flows when wood is transported. During low flow events, some woody material may be passed through the FRO Alternative.

4.3.1.1.3 Channel Migration

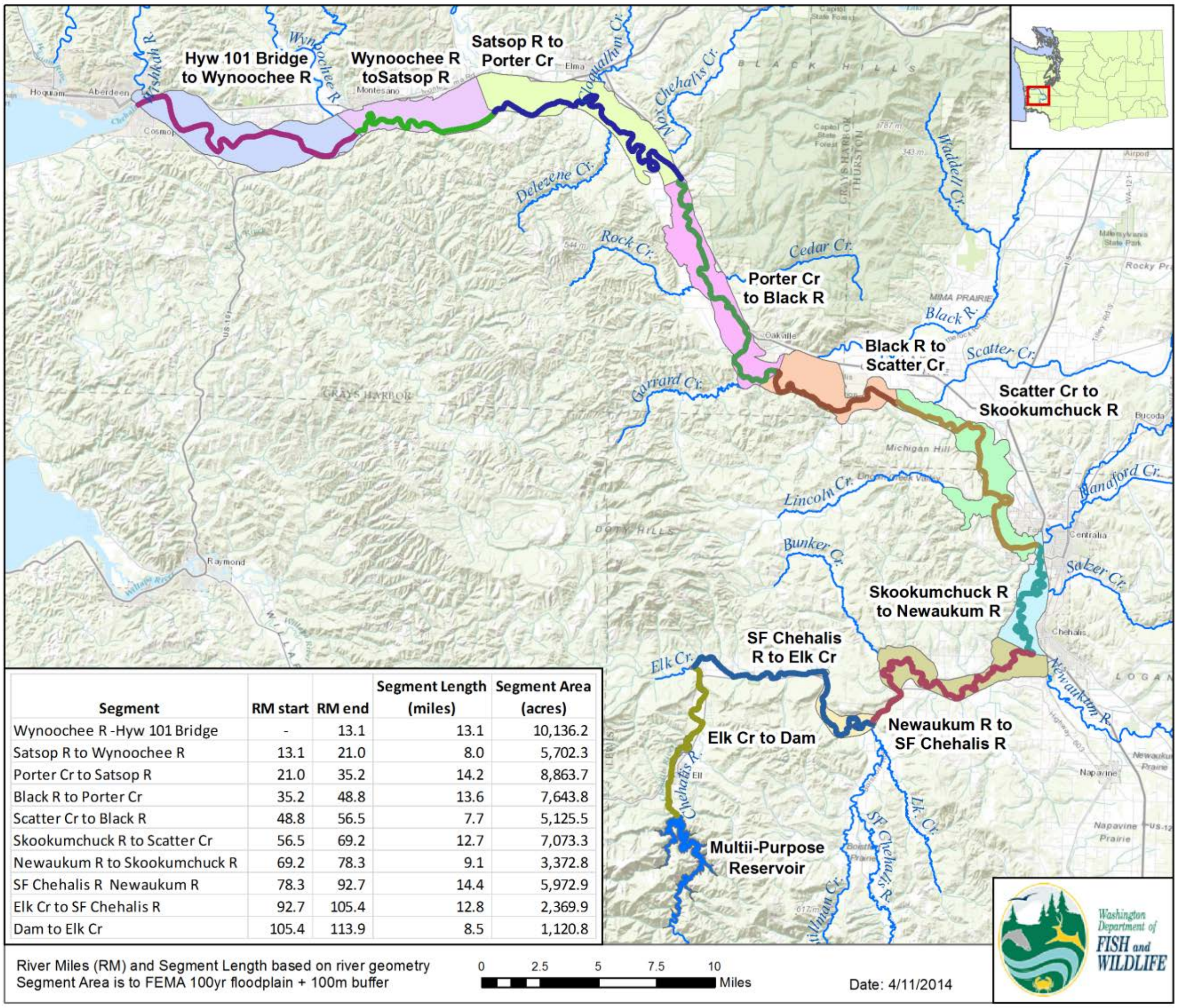
Based on analysis of migration rates between 1945 and 2013, channel migration appears to take place even during small peak flood events in unconfined areas in response to flow against banks on the outside of meanders (Watershed GeoDynamics and Anchor QEA 2014). Therefore, under both dam alternatives bank erosion and channel migration processes would likely continue because only small reductions in the 1- to 2-year peak flow magnitudes will occur under the dam alternatives. However, reduction in sediment supply may slow aggradation-induced bank erosion under the MPD Alternative scenario. Over time, encroachment of riparian vegetation as a result of the reduction of large flood peaks could stabilize banks and reduce channel migration rates. This effect will be most pronounced in upstream areas. Major channel avulsions are unlikely to occur as frequently under either scenario because large woody material moving during huge flood events upstream of the facility will be trapped, at least temporarily in the reservoir. Also, depletion of large wood following major flood events as occurred immediately after the 2007 flood will further limit wood supply to the system. Therefore, channel-spanning log jams will be less likely to form, and any effects these have on in- and off-channel habitat formation will be reduced.

4.3.1.2 FLOODPLAIN INUNDATION

To model the effects of changes in floodplain inundation on salmon using the EDT model, acreages of off-channel habitat (oxbows, back swamps, riverine ponds, and the channels that connect them to the main channel or its side channels) were calculated from water surface elevations at 445 mainstem locations. These locations represented cross-sections at which flows were modeled using HEC-RAS (see Appendix B for more detail on inundation modeling methods applied for EDT analyses).

For Other Fish and Non-fish Species, area of inundation was mapped using HEC-RAS and RASMapper water depth raster surfaces for 500-year, 100-year, 20-year, 10-year, and 2-year flood events under the current (without dam) and with dam conditions. The river was separated into 10 segments of varying length with segment breakpoints based on major tributaries (Figure 4.2).

Figure 4.2
Chehalis River Segments (RM and Segment Lengths) Used for Floodplain Inundation Modeling



Segment	RM start	RM end	Segment Length (miles)	Segment Area (acres)
Wynoochee R -Hyw 101 Bridge	-	13.1	13.1	10,136.2
Satsop R to Wynoochee R	13.1	21.0	8.0	5,702.3
Porter Cr to Satsop R	21.0	35.2	14.2	8,863.7
Black R to Porter Cr	35.2	48.8	13.6	7,643.8
Scatter Cr to Black R	48.8	56.5	7.7	5,125.5
Skookumchuck R to Scatter Cr	56.5	69.2	12.7	7,073.3
Newaukum R to Skookumchuck R	69.2	78.3	9.1	3,372.8
SF Chehalis R Newaukum R	78.3	92.7	14.4	5,972.9
Elk Cr to SF Chehalis R	92.7	105.4	12.8	2,369.9
Dam to Elk Cr	105.4	113.9	8.5	1,120.8

4.3.1.3 JUVENILE SALMON MOVEMENT

Preliminary results of juvenile fish tagging studies conducted in 2013 and 2014 were not explicitly incorporated into the analyses. However, the results were discussed during implementation of the studies and are presented in this section to provide the reader with the latest biological data collected on juvenile salmon movement in the basin.

In 2013, WDFW tagged and released a total of 1,614 juvenile coho salmon and 231 juvenile winter-run steelhead in the mainstem Chehalis River between River Kilometer (RKm) 166 (Jones Creek confluence) and RKm 174 (the proposed dam site) using passive integrated transponder (PIT) tags. Fish were tagged in late July at four mainstem locations and monitored through late September 2013 at four detection sites. These detection sites included single PIT tag detectors installed in Jones, Stowe, and Rock creeks just upstream from their confluence with the Chehalis River, and a double PIT tag detector array installed in the mainstem Chehalis River near the proposed dam site. The double array allowed both the timing and direction of fish movement to be documented at the dam site location. Results of the study indicated that tagged juvenile coho salmon and steelhead:

- Ranged up to 7.8 kilometers from their release site
- Moved between mainstem and tributary habitat for summer rearing
- Increased their movements once temperatures started to decrease and fall rains began
- Moved upstream and downstream past the proposed dam site throughout the study period, and
- Displayed a fairly consistent diel pattern at the dam site comprises upstream movement in the morning and downstream movement during evening

In 2013 and 2014, the USGS conducted two studies of juvenile salmon movements in the Chehalis River using radio telemetry. Seven fixed mainstem monitoring sites from Aberdeen to Pe Ell were established for these studies. The first effort started in October 2013 and was terminated in January 2014; it was designed to monitor the use of overwinter habitat by juvenile coho salmon and winter-run steelhead. A total of 50 juvenile salmon were tagged and released upstream from the proposed dam site located 7.5 RKm upstream of the town of Pe Ell, Washington, and 50 juvenile salmon were tagged and released downstream from the proposed dam site 4 RKm downstream of Pe Ell. Radio-tagged fish spent the most time in the reaches closest to their release sites, although radio-tagged coho salmon and steelhead were detected as far downstream as the Newaukum River. Coho salmon released upstream from the proposed dam site were primarily detected at the Pe Ell and Doty fixed site locations, with reduced detections at the South Fork and Newaukum sites. For coho salmon released downstream from the proposed dam site, about half of the fish were detected at the Doty site, with reduced detections at the South Fork and Newaukum sites. Steelhead displayed less movement than coho salmon, with detections as far downstream as Doty for fish released upstream from the dam site and as far downstream as the South Fork for fish released downstream from the dam site.

The second effort was initiated in April 2014. It was designed to monitor the outmigration behavior of juvenile coho salmon, Chinook salmon, and steelhead. A total of 335 juvenile salmon from these species was collected at the WDFW inclined plane trap located near Rochester, Washington, tagged, transported, and released at approximately the same location used for fish released upstream from the dam site during the fall 2013 effort discussed previously. Preliminary results indicate these fish actively migrated downstream, as the coho salmon, steelhead, and Chinook salmon were detected at the furthest downstream fixed monitoring station located near Aberdeen, Washington.

4.4 Methods: Analyzing Salmon Species

Effects of flood retention alternatives on salmon were analyzed using two species-habitat models: EDT and SHIRAZ. EDT provided a detailed evaluation of habitat in the context of the species' life history for the Chehalis watershed upstream of and including the Wynoochee River. EDT evaluates a habitat condition and compares conditions at different points in time under various alternatives, but does not track fish population dynamics through time. For this Project, SHIRAZ was developed to look exclusively at the effects of the water retention alternatives on mainstem Chehalis River salmon populations. It includes stochastic variation in environmental conditions and population dynamics and thus, provides insights into how salmon populations respond over time to changes in habitat.

The 2003 EDT model (Mobrand Biometrics, Inc. 2003) was updated to the current EDT platform (termed EDT3) by incorporating mainstem river habitat data collected in 2012 by Anchor QEA and 2013 by WDFW. The updated model was used to assess the effects of water retention alternatives on salmonid populations in 14 sub-basins from the Wynoochee River to the upper Chehalis River. Table 4.3 describes the environmental changes that were incorporated into the EDT model and used to evaluate water retention alternatives.

Table 4.3
Summary of Environmental Changes Assumed in the Water Retention Alternatives

AREA	FLOOD RETENTION ONLY ALTERNATIVE	MULTI-PURPOSE DAM ALTERNATIVE
Lower Chehalis: Wynoochee River to Newaukum River	No change from current condition.	Small changes in flow and temperature.
Middle Chehalis: Newaukum River South Fork River	No change in flow or temperature from current, small reduction in bed scour, reduced wood, reduced fine sediment, coarsening of habitat types.	Diminishing flow and temperature changes, larger reduction in bed scour, greater reduction in wood, reduced fine sediment, coarsening of habitat types.
Upper Chehalis: South Fork to the dam site	No change in flow or temperature from current, small reduction in bed scour, reduced wood, reduced fine sediment, coarsening of habitat types.	Significant flow (increase) and temperature (decrease) downstream from the dam site in summer and fall, larger reduction in bed scour, greater reduction in wood, reduced fine sediment, coarsening of habitat types.
Proposed dam site	Relatively high juvenile and adult passage survival (88% combined survival).	Lower juvenile and adult passage survival (60% combined survival).
Upper Chehalis: Upstream from the dam	Degradation of riverine conditions due to inundation. Three scenarios were analyzed differing in regard to amount of habitat affected upstream from the dam.	Conversion of riverine reaches to limnetic and littoral reservoir habitats within reservoir footprint. Relatively large decrease in water temperature downstream from the dam during summer and fall.

Three scenarios for the FRO Alternatives were evaluated using EDT. The scenarios were designated FRO25, FRO50, and FRO100, and represented whether 25%, 50% or 100% of the habitat upstream from the FRO dam, respectively, would be degraded as a result of impounding flood flows. These scenarios apply to the areas upstream of the dam that would be inundated during water retention events (approximately 7 miles). The scenarios were developed to evaluate uncertainty associated with how the frequency of FRO use (within and between years) effected habitat conditions for salmon upstream from the dam. The scenarios differed only in respect to conditions upstream from the dam and were identical with respect to their effect on conditions downstream from the proposed dam. An expanded discussion of the assumptions used in assessing water retention alternatives with the EDT model is presented in Appendix B.

SHIRAZ models developed in 2012 were updated in 2014 to incorporate new information on salmon population life histories. This included how salmon utilized different parts of the river, existing habitat conditions, potential changes to habitat that may occur if FRO or an MPD is constructed, and assumptions regarding the effectiveness of fish passage facilities under both water retention alternatives. Incorporating the updated information required revising the habitat parameters in SHIRAZ that related river conditions to fish survival, to improve the calibration of modeled to observed numbers of salmon spawners. See Appendix C for a detailed description of the SHIRAZ updates and methods used in the analyses.

4.5 Results: Salmon Species

4.5.1 ECOSYSTEM DIAGNOSIS & TREATMENT MODEL

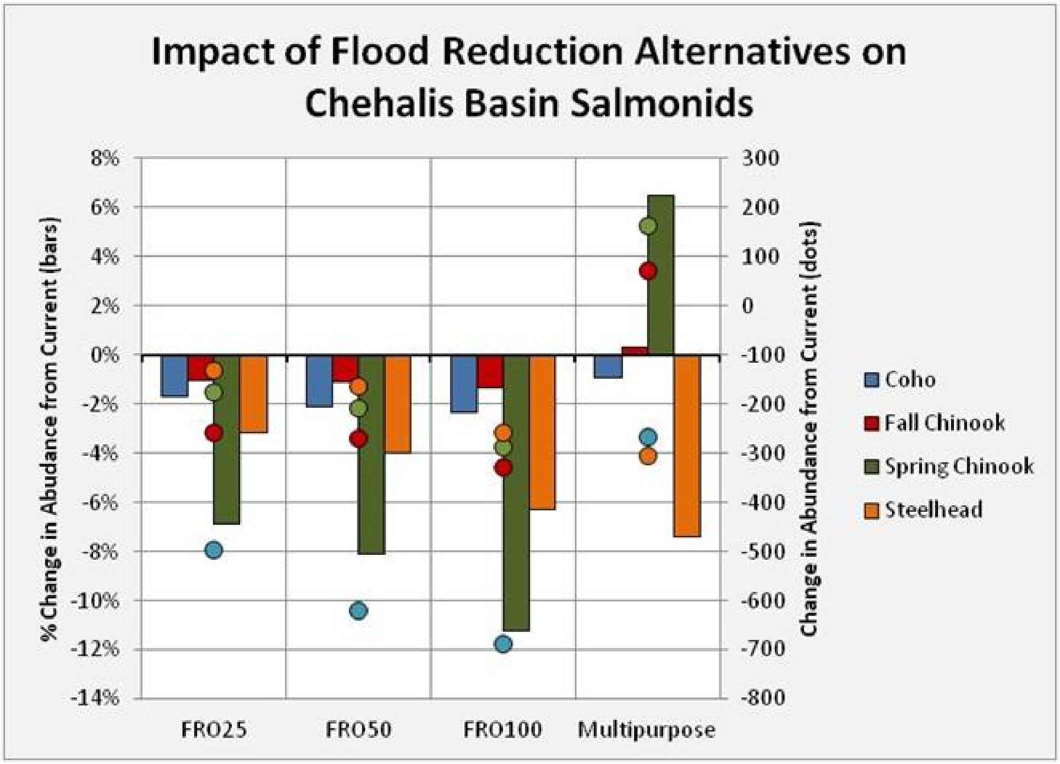
Estimated effects by flood retention alternatives on the four salmonid species modeled are first considered at the basin scale. Next, the results are divided into three groups of sub-populations based on differing degrees of exposure to the effects of the water retention alternatives. The lower Chehalis River group included all sub-populations from the Wynoochee River to the Skookumchuck River. These sub-populations are farthest from the proposed dam site and least exposed to the effects of the dam operations. The middle Chehalis River group included all sub-populations between the Skookumchuck River and the South Fork Chehalis River. This group is affected by the anticipated flow and geomorphic changes downstream from the proposed dam site. The third group is the upper Chehalis sub-populations, which were the most directly affected by the operations of the proposed dam and the upstream effects of impoundments.

4.5.1.1 BASIN SCALE

The effects of water retention alternatives on habitat potential at a species level across the entire study area (i.e., the entire Chehalis basin modeled in EDT) are shown in Figure 4.3. Changes in species abundance due to the FRO Alternative were negative (i.e., effects) for all species. This reflected the varying degrees of habitat change upstream from the proposed dam in the three FRO Alternatives as well as assumed geomorphic changes downstream from the dam site.

The MPD Alternative had negative effects on coho salmon and winter-run steelhead but positive effects on fall-run and spring-run Chinook salmon (Figure 4.3). The negative effect on coho salmon and winter-run steelhead resulted from the relatively high adult and juvenile passage mortality assumed at the dam site and geomorphic changes downstream from the dam site. The positive effect of the MPD Alternative on spring-run Chinook salmon, and to a much smaller degree, fall-run Chinook salmon resulted from the reduction in water temperature downstream from the proposed dam associated with the assumption that cool water from below the thermocline in the proposed reservoir would be released each year. Spring-run Chinook salmon in particular responded favorably to actions that reduced temperatures in the mainstem because of the assumption that these fish hold prior to spawning near their spawning reaches and are susceptible to pre-spawn mortality due to high temperature while holding for long periods. Fall-run Chinook salmon increased in abundance due to benefits associated with reduced water temperatures below the MPD Alternative during spawning. Both runs of Chinook salmon also benefitted somewhat from reduced scour associated with water retention alternatives and flow released from the MPD Alternative.

Figure 4.3
Species-level Changes in Salmonid Habitat Potential in the Chehalis Basin Resulting from Water Retention Alternatives Relative to Current Habitat Potential



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

4.5.1.2 LOWER CHEHALIS RIVER SUB-POPULATIONS

Modeled changes in the Chehalis River downstream from the Skookumchuck River confluence resulting from the water retention alternatives were limited to minor changes in flow and temperature (Table 4.3). Small changes in flow under the MPD Alternative primarily affected channel width and the modeled amount of off-channel floodplain habitat. No difference existed in conditions in the lower Chehalis River between the three FRO Alternatives, so only results from the FRO50 Alternative are shown in Table 4.4.

Changes in projected abundance of salmonids for the lower Chehalis sub-populations relative to the current (no-dam) habitat condition are shown in Table 4.4. The FRO50 Alternative did not change conditions in the lower Chehalis River relative to current conditions, and therefore had no effect on the abundance of these populations (Table 4.4). The MPD Alternative reduced and extended high flow conditions resulting in small changes in monthly flow in the mainstem Chehalis River, which resulted in small increases in the abundance of some lower Chehalis River salmon populations, primarily for lower Chehalis River mainstem populations.

Table 4.4
Changes in Abundance for Lower Chehalis River Salmonid Sub-populations Resulting from Water Retention Alternatives

SPECIES	SUB-POPULATION	FRO50	MULTI-PURPOSE DAM
Coho salmon	Wynoochee	0%	0%
	Satsop	0%	0%
	Lower Chehalis Tributaries	0%	0%
	Black River	0%	0%
	Scatter Creek	0%	2%
Fall-run Chinook salmon	Wynoochee	0%	0%
	Satsop	0%	0%
	Lower Mainstem	0%	1%
	Lower Chehalis Tributaries	0%	0%
	Black River	0%	1%
Spring-run Chinook salmon	Lower Mainstem	0%	8%
	Skookumchuck	0%	1%
Winter-run steelhead	Wynoochee	0%	0%
	Satsop	0%	0%
	Lower Mainstem	0%	6%
	Lower Chehalis Tributaries	0%	0%
	Skookumchuck	0%	0%

Note: No difference existed in conditions in the lower Chehalis River between the three FRO Alternatives, so only results from the FRO50 Alternative are shown in this table.

4.5.1.3 MIDDLE CHEHALIS RIVER SUB-POPULATIONS

In the middle Chehalis River area (Skookumchuck River to South Fork Chehalis River), a broad suite of effects of the water retention alternatives was assumed (Table 4.3). Conditions in the middle Chehalis area were the same for all of the FRO Alternatives and so only results from the FRO50 Alternative are shown in Table 4.5. Middle Chehalis mainstem and tributary populations are quite small and the proportional changes presented in Table 4.5 represent small changes in actual fish abundance.

The FRO50 Alternative reduced the abundance of all mid-Chehalis salmonid populations relative to the current condition (Table 4.5). This was due to the assumed reduction in large wood supply, a coarsening of habitat types due to the dam capturing sediment, and the reduction in habitat-forming flood flows as a result of the dam.

The MPD Alternative increased fall-run Chinook salmon in the middle Chehalis area due the reduction in bed scour and the decrease in water temperature during key life stages. Spring-run Chinook salmon also increased in the segment; although the percent change from current is undefined because the abundance under current habitat condition was zero in the EDT model. For both fall-run and spring-run Chinook salmon, the increase in abundance in the segment under the MPD Alternative was due to the reduction in water temperature during the late summer and fall period.

Table 4.5
Changes in Abundance for Middle Chehalis River Salmonid Sub-populations Resulting from Water Retention Alternatives

SPECIES	SUB-POPULATION	FRO50	MULTI-PURPOSE DAM
Coho salmon	Middle Chehalis Tributaries	-13%	-4%
	Newaukum River	0%	0%
	South Fork Chehalis	-6%	-8%
	Skookumchuck to South Fork	0%	0%
Fall-run Chinook salmon	Middle Chehalis Tributaries	-4%	-5%
	Newaukum River	0%	1%
	South Fork Chehalis	-1%	-1%
	Skookumchuck to South Fork	-5%	12%
	South Fork Chehalis	-1%	-1%
Spring-run Chinook salmon	Middle Chehalis Tributaries	0%	0%
	Newaukum River	0%	1%
	South Fork Chehalis	-3%	-5%
	Skookumchuck to South Fork	0%	Undefined
Winter-run steelhead	Middle Chehalis Tributaries	-8%	-7%
	Newaukum River	0%	0%
	South Fork Chehalis	-2%	-3%
	Skookumchuck to South Fork	0%	0%

4.5.1.4 UPPER CHEHALIS RIVER SUB-POPULATIONS

The greatest habitat changes resulting from the flood retention alternatives occurred in the populations upstream from the South Fork Chehalis River (Table 4.6. The area upstream from the proposed FRO dam was affected by the periodic inundation for flood control at levels in relation to the three FRO Alternatives evaluated (FRO25, FRO50, and FRO100). The MPD Alternative assumed that all habitat within the reservoir footprint would be converted from riverine to littoral (i.e., shoreline) and limnetic (i.e., open surface water) reservoir habitat.

The water retention alternatives affected all upper Chehalis salmonid populations (Table 4.6), but the greatest effect occurred to Chehalis mainstem from the South Fork to the proposed dam site and the upper Chehalis population upstream from the proposed dam site populations (Figure 4.4). Upstream from the proposed dam site, the FRO Alternatives resulted in progressively greater negative effects for all populations as increasing proportion of habitat were affected by the dam (Figure 4.4). The FRO Alternatives resulted in appreciable decreases in habitat potential upstream from the dam site for all species. Habitat potential upstream from the proposed dam site was reduced from 25 to 65% under the FRO Alternatives for all four species.

For all species except coho salmon, the MPD Alternative had the greatest negative effect on populations upstream from the proposed dam site (Figure 4.4). Spring-run and fall-run Chinook salmon and steelhead habitat potential was reduced around 80% upstream from the proposed dam site under the MPD Alternative. These reductions were the result of loss of mainstem and tributary spawning habitat under the MPD reservoir and the relatively high juvenile and adult passage mortality at the dam (Table 4.3). In addition, these three species did not benefit from the large expanse of littoral and limnetic habitat in the reservoir. Spring-run and fall-run Chinook salmon were assumed to move downstream past the dam in the spring with little opportunity for rearing and feeding in the reservoir. Although winter-run steelhead that spawned in the upper Chehalis were assumed to spend considerable time in freshwater prior to emigration, evidence from the upper Cowlitz Falls reservoir suggested steelhead would not use the reservoir for juvenile rearing during summer.

Habitat potential for coho salmon upstream from the proposed dam site was reduced by only about 15% under the MPD Alternative (Figure 4.4). Available evidence from the upper Cowlitz Falls reservoir indicated that coho salmon utilize reservoir habitats while residing in freshwater during summer and benefit from the increased feeding opportunities available in a reservoir relative to river reaches (Kohn, pers. comm. 2014). The large extent of the proposed reservoir, although it eliminated spawning habitat, provided ample juvenile rearing for coho salmon in the model. However, coho salmon were still subject to the relatively high assumed passage mortality at the dams, which resulted in an overall reduction in abundance under the MPD Alternative.

The water retention alternatives also had appreciable effects on populations in the mainstem from the South Fork to the proposed dam site (Figure 4.4). Conditions below the proposed dam for the three FRO Alternatives were assumed to be the same among the three alternatives and reflected reductions in large wood, lower bed scour and a coarsening of habitats. As a result, the changes in species habitat potential were nearly identical for all FRO Alternatives. The greatest negative change under the FRO Alternatives was for coho salmon and the least change was for fall-run Chinook salmon (Figure 4.4). Adult salmon from the Elk Creek sub-population were assumed in the model to hold in Elk Creek. As such, they would not achieve benefits of the cool water releases from the MPD Alternative. In the model, juveniles from Elk Creek were assumed to move into the mainstem river and while there were exposed to reduced wood and habitat changes in the mainstem associated with the FRO Alternatives during spring prior to emigrating from the system.

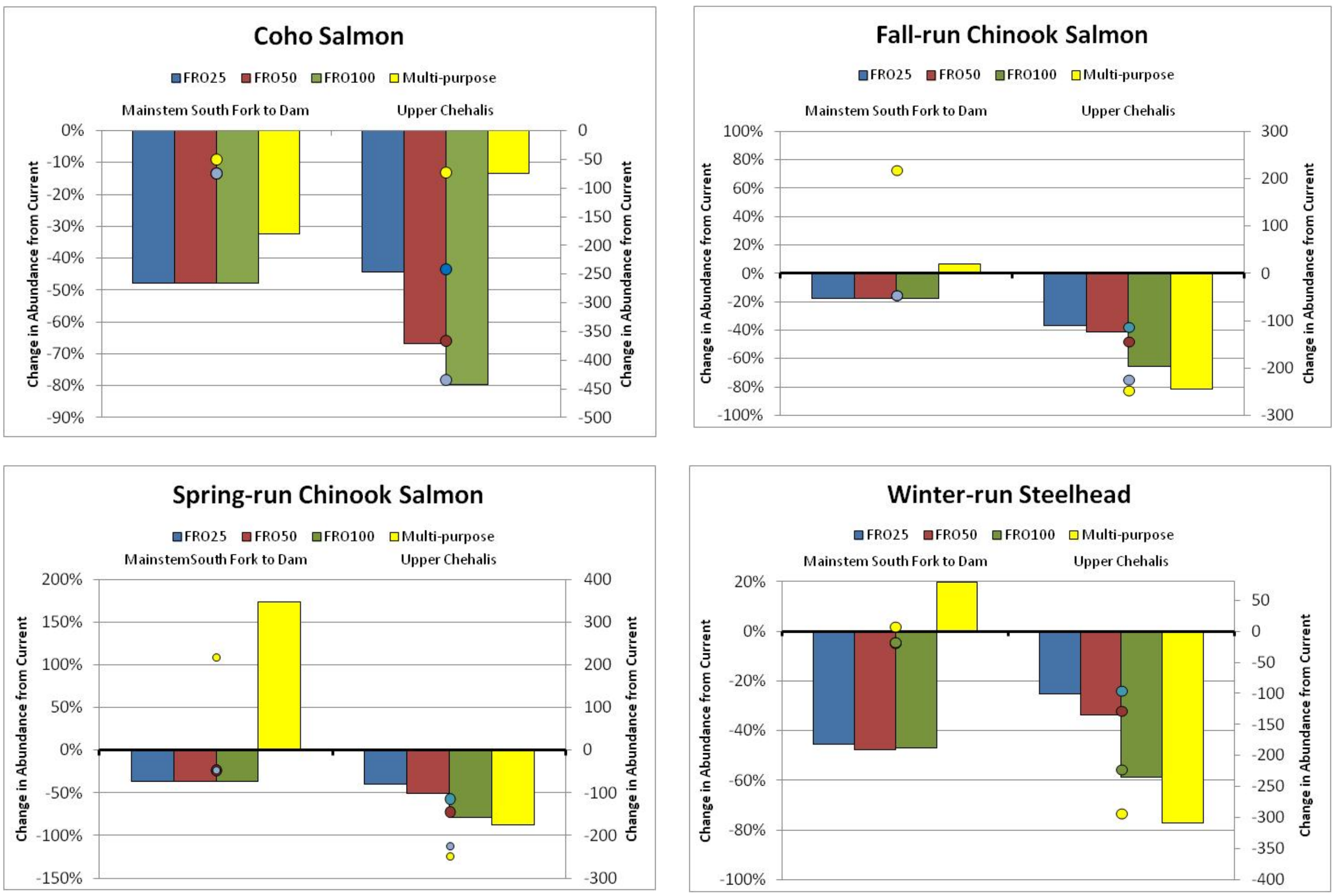
The MPD Alternative had a positive effect of spring-run and fall-run Chinook salmon and steelhead downstream from the proposed dam site but a negative effect on coho salmon (Figure 4.4). Spring-run Chinook salmon habitat potential downstream from the dam increased by 174% while fall-run Chinook salmon habitat potential increased 7% and steelhead habitat potential increased by 20%.[1] These positive changes in habitat potential from the MPD Alternative were the result of releases of cooler water from the dam in summer and fall as the reservoir was evacuated to create flood storage. The positive effect of the cooler water was greatest for spring-run Chinook salmon because of the benefit to the pre-spawning and spawning life stages. Water temperatures during summer months downstream from the proposed dam site in the modeled current condition were approximately 70^{o}F (21.1^{o}C), which reduced adult fish survival. Spring-run Chinook salmon enter the river in the spring and must hold over summer before spawning in the fall making them particularly susceptible to high summer and fall water temperature. Hence the significant reduction in summer and fall water temperature below the MPD appreciably increased pre-spawning and spawning survival in the model. Fall-run Chinook salmon do not have the extended pre-spawning life stage of spring-run Chinook salmon but did benefit from cooler temperature during the fall spawning period. Winter-run steelhead spawn in winter but the cooler water from the MPD Alternative improved summer juvenile survival. Coho salmon spawn late in the fall and early winter and did not get a positive change in survival due to the cooler water from the MPD. Instead, coho habitat potential was reduced by the assumed reduction in large wood and habitat changes downstream from the dam.

The strong positive response of spring-run Chinook salmon in the model is primarily due to the effect of cooler summer water on pre-spawning survival. This assumes that spring-run Chinook salmon enter the river in spring and hold over summer in the mainstream Chehalis River between the South Fork and proposed dam site prior to spawning in the fall in the same area. Where adult spring-run Chinook salmon hold during summer in the Chehalis River is not known and represents a key uncertainty. Certainly summer water temperature must be a significant factor affecting distribution and survival of spring-run Chinook salmon in the Chehalis system. It is

[1] Note that these changes are only for the sub-populations from the South Fork to the proposed dam; species level impacts of the FRO Alternatives were considerably less (Figure 4.3).

possible that spring-run Chinook salmon hold over in tributaries such as the Skookumchuck River that have cooler water during summer, or that they find localized pockets of cool water in the mainstem or elsewhere. In this case, the current pre-spawning survival of spring-run Chinook salmon would be higher than was calculated in the model and the positive change in habitat potential as a result of the MPD would be less than shown in Figure 4.4. Research currently underway by USGS and WDFW should provide information on summer holding behaviors and locations of spring-run Chinook salmon. Incorporating this information in future studies could lead to revisions in the current assessment of the MPD Alternative on this run of Chinook salmon.

Figure 4.4
Effects of the Flood Retention Alternatives on Upper Chehalis Salmonid Populations



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

Table 4.6
Changes in Abundance for the Upper Chehalis River Sub-populations Resulting from Water Retention Alternatives

SPECIES	SUB-POPULATION	FRO25	FRO50	FRO100	MULTI-PURPOSE DAM
Coho salmon	Mainstem South Fork to Dam	-48%	-48%	-48%	-32%
	Elk Creek	-8%	-8%	-8%	-7%
	Upper Chehalis	-44%	-67%	-80%	-13%
Fall-run Chinook salmon	Mainstem South Fork to Dam	-18%	-18%	-18%	7%
	Elk Creek	-5%	-5%	-5%	-2%
	Upper Chehalis	-37%	-41%	-65%	-98%
Spring-run Chinook salmon	Mainstem South Fork to Dam	-37%	-37%	-37%	174%
	Elk Creek	-10%	-10%	-10%	-15%
	Upper Chehalis	-40%	-51%	-79%	-88%
Winter-run steelhead	Mainstem South Fork to Dam	-45%	-48%	-47%	20%
	Elk Creek	-4%	-4%	-4%	-7%
	Upper Chehalis	-25%	-34%	-59%	-77%

4.5.2 SHIRAZ MODEL

Mainstem Chehalis River salmon population sizes were estimated for an 80-year period (from year 2020 to 2099). Population estimates were calculated based on 50 simulation runs for each species, which allowed for the model to apply observed variability in environmental conditions (e.g., temperatures and flows) to the salmon population estimates. Model inputs for environmental data were applied as described in the 2012 study (Anchor QEA 2012b) with updates to incorporate new data (see Appendix C). The FRO Alternative in the SHIRAZ is most comparable to the FRO100 scenario described for the EDT analysis.

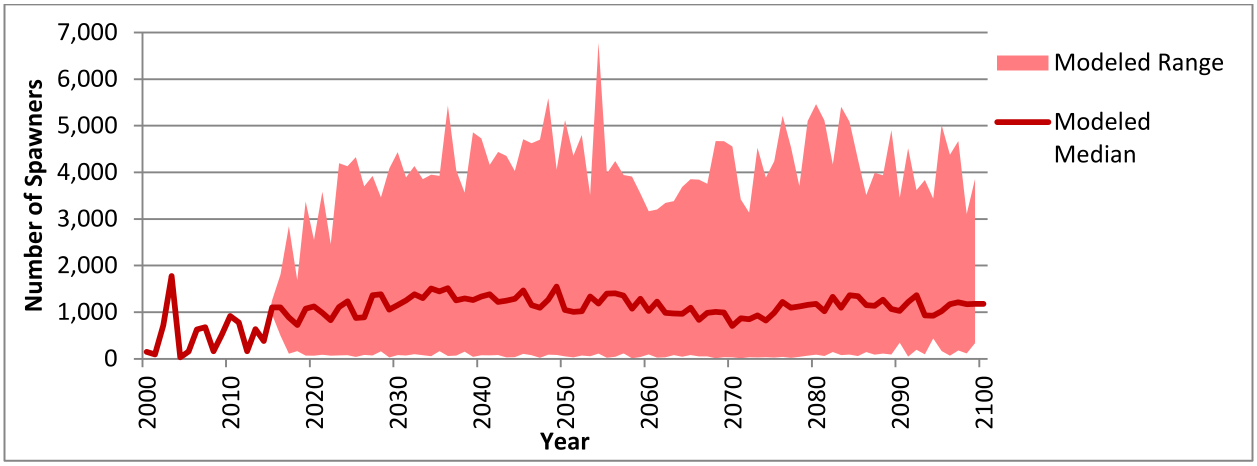
For each year, the median estimated number of adult spawners was calculated using the outputs of the 50 model simulation runs. Model results presented in Figures 4.5 through 4.13 show the median number of adult spawners predicted each year. As a median, the line connecting the modeled medians for each year of the analysis period shows less year-to-year variability than is apparent in any of the individual simulations. To present an indication of the variability among simulations, these figures also show the modeled range, which is the range between the highest and lowest estimates produced for each simulation year. The models predict the continuation of existing conditions which incorporated empirically observed data through 2012; therefore, the modeled range (between minimum and maximum estimates for each simulation year) begin in year 2013 in these figures.

4.5.2.1 BASELINE CONDITIONS

Assuming the continuation of existing conditions, the median predicted number of spring-run Chinook salmon spawners was stable throughout the analysis period (Figure 4.5). The median number of adults spawners estimated in the 50 simulations was between 800 and 1,400 fish. These modeled estimates are higher than WDFW's observation-based estimates in recent years. Between 1991 and 2013, the median number of spring-run Chinook salmon spawners estimated by WDFW ranged between 47 and 1,388 with an average of 474 fish.

Variability in the environmental conditions predicted in the model simulations resulted in annual estimates of spring-run Chinook salmon spawners ranging from 12 to 6,800 fish. Between years 2020 and 2099, the lowest estimated number of spawners was estimated to be fewer than 100 during 80% (64 of 80) of the analysis years. Thus, despite the median estimates, the variable environmental conditions that may occur during the analysis period may result in years when relatively few spring-run Chinook salmon adults return to spawn in the mainstem Chehalis River.

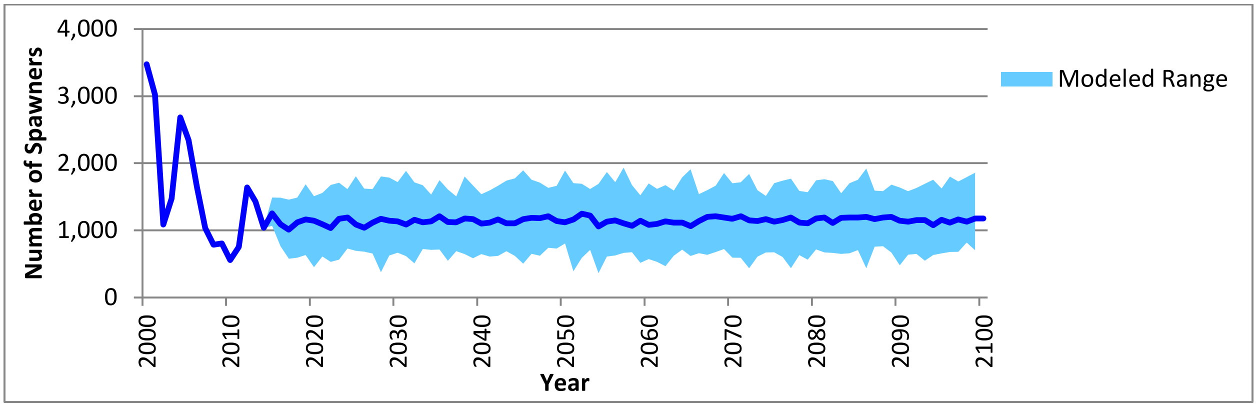
Figure 4.5
Example of Simulations Estimating Spring-run Chinook Salmon Spawners Assuming the Continuation of Existing Conditions



The predicted median number of winter-run steelhead spawners was stable throughout the analysis period under the assumption of continued existing conditions (Figure 4.6). The median number of adults spawners estimated in the 50 simulations was between 1,000 and 1,250 fish. This range is consistent with the number of 1,168 winter-run steelhead spawners estimated by WDFW during the 1996 to 2012 period. During this time, the WDFW estimates ranged between 538 and 1,970 spawners with an average of 1,147.

Variability in the environmental conditions predicted in the model simulations results in annual estimates of adult winter-run steelhead spawners ranged from approximately 350 to 2,000 fish. Between years 2020 and 2099, the lowest estimated number of spawners was estimated to be fewer than 500 during 11% (9 of 80) of the analysis years. When considering the maximum estimated number of adult winter-run steelhead spawners, the model simulations estimate more than 1,500 fish could return to spawn during each year of the analysis period.

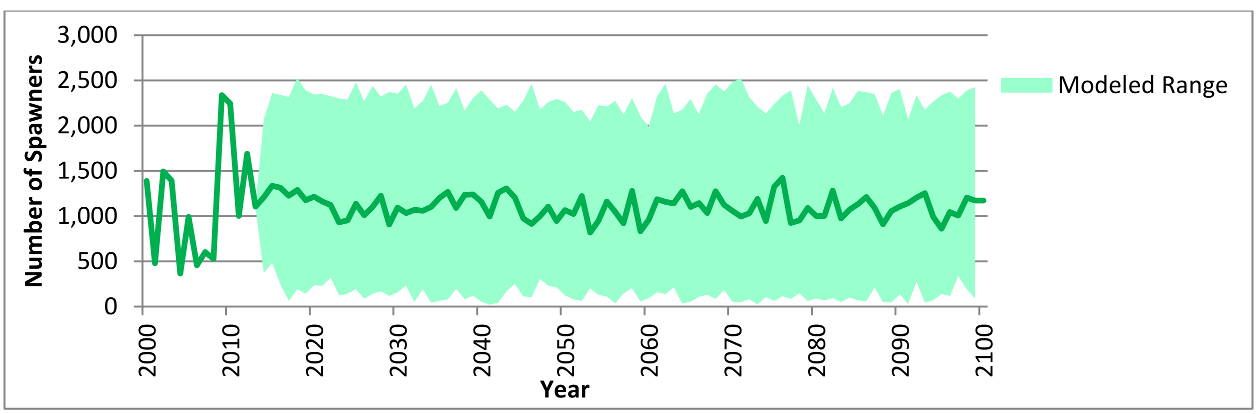
Figure 4.6
Example of Simulations Estimating Winter-run Steelhead Spawners Assuming the Continuation of Existing Conditions



The median predicted number of coho salmon spawners assuming the continuation of existing conditions was stable throughout the analysis period (Figure 4.7). The median number of adult spawners estimated in the 50 simulations was between 800 and 1,400 fish. These modeled estimates are higher than WDFW's observation-based estimates in recent years. Between 1998 and 2012, the number of coho salmon spawners estimated by WDFW ranged between 103 and 1,940, with an average of 811 fish. While this estimated future condition did not match recent observations, the model remains valid as a tool to compare the relative changes between scenarios.

Variability in the environmental conditions predicted in the model simulations results in annual estimates of adult spawner ranging from 22 to 2,500 fish. Between the years 2020 and 2099, the lowest estimated number of spawners was estimated to be fewer than 100 fish during 36 (45%) of the analysis years. Thus, despite the median estimates, the variable environmental conditions that may occur during the analysis period may result in years when relatively few coho salmon adults return to spawn in the mainstem Chehalis River. When considering the maximum estimated number of adult spawners, the model simulations estimated that more than 2,000 fish could return during all but one year in the analysis period.

Figure 4.7
Example of Simulations Estimating Coho Salmon Spawners Assuming the Continuation of Existing Conditions



4.5.2.2 WATER RETENTION ALTERNATIVES

For each salmon species analyzed using SHIRAZ, estimated population size decreased under the FRO Alternative. Under the MPD Alternative, an increase in spring-run Chinook salmon numbers was predicted, but coho salmon and winter-run steelhead numbers were predicted to decrease. Changes in population size predicted by the model were immediate, after which the population numbers were relatively stable for the remainder of the analysis period. The SHIRAZ model estimated less variability in the number of spawners compared to historic and recent observations, such that high return years would not occur if a dam was in place. The estimated number of salmon and steelhead spawners with each dam alternative is presented in Figures 4.8 through 4.13.

Figure 4.8
Estimated Number of Spring-run Chinook Salmon Spawners with the Flood Retention Only Dam

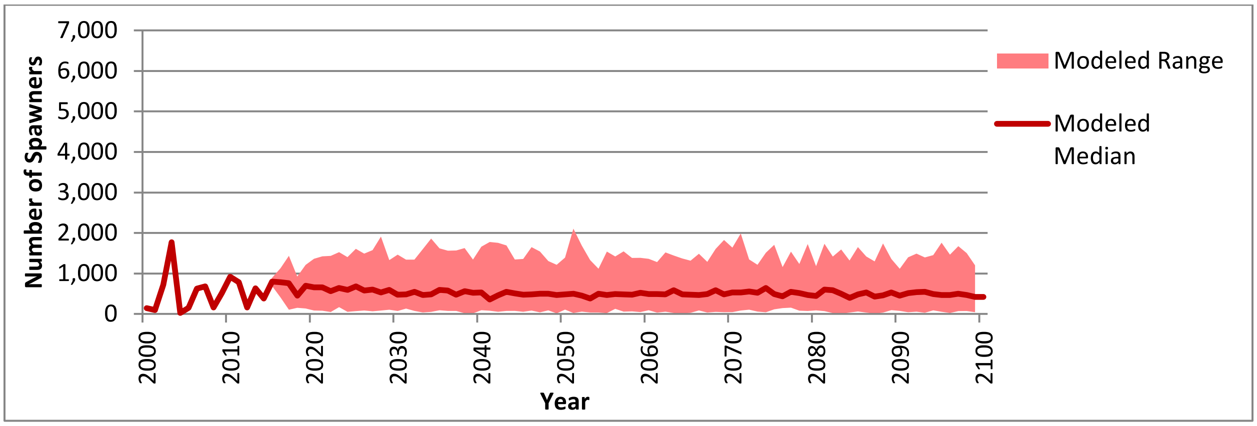


Figure 4.9
Estimated Number of Spring-run Chinook Salmon Spawners with the Multi-purpose Dam

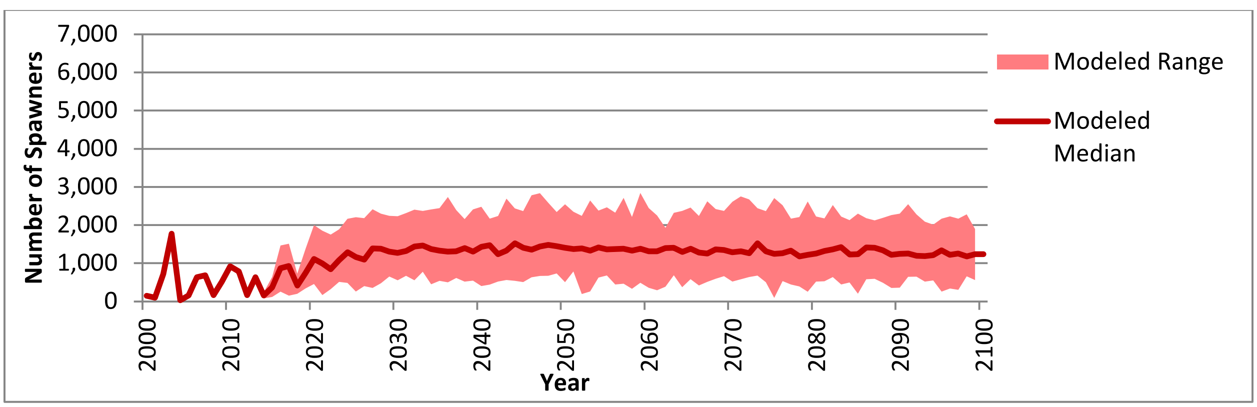


Figure 4.10
Estimated Number of Winter-run Steelhead Spawners with the Flood Retention Only Dam

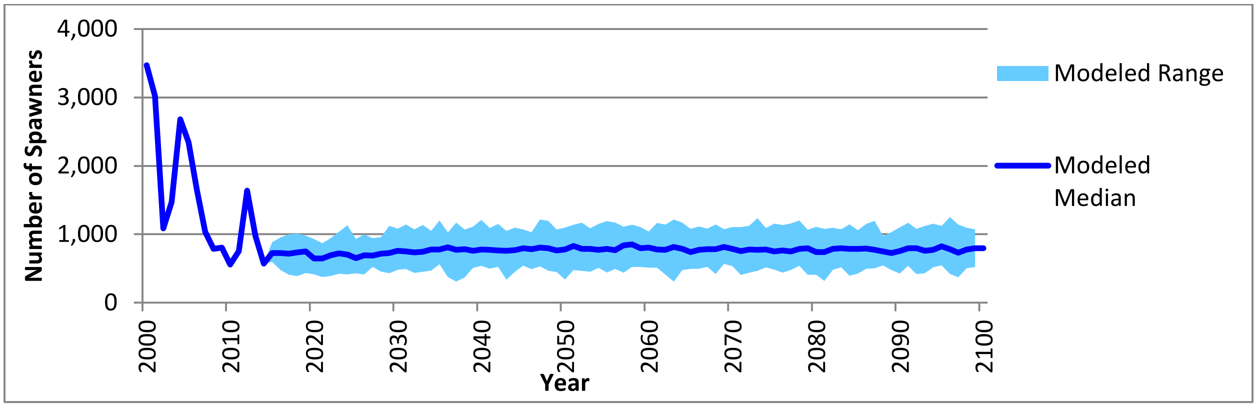


Figure 4.11
Estimated Number of Winter-run Steelhead Spawners with the Multi-purpose Dam

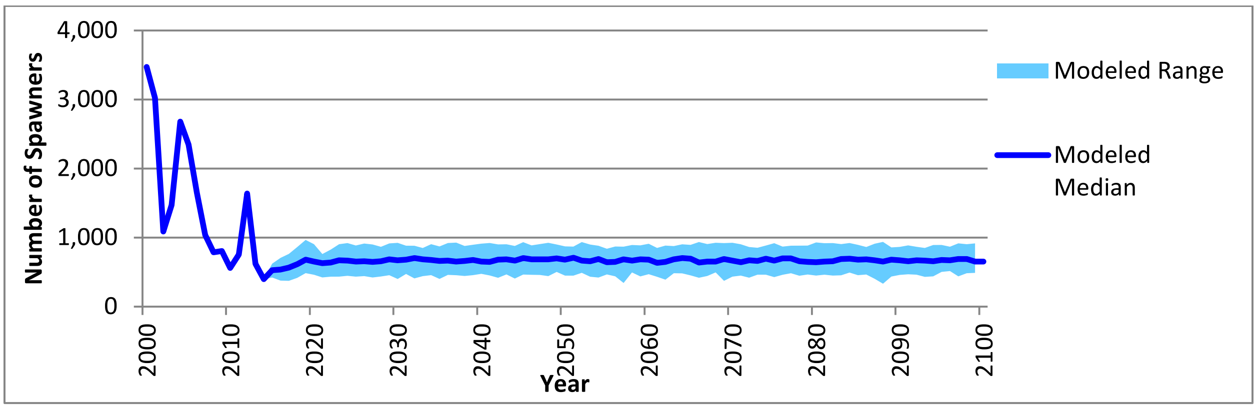


Figure 4.12
Estimated Number of Coho Salmon Spawners with the Flood Retention Only Dam

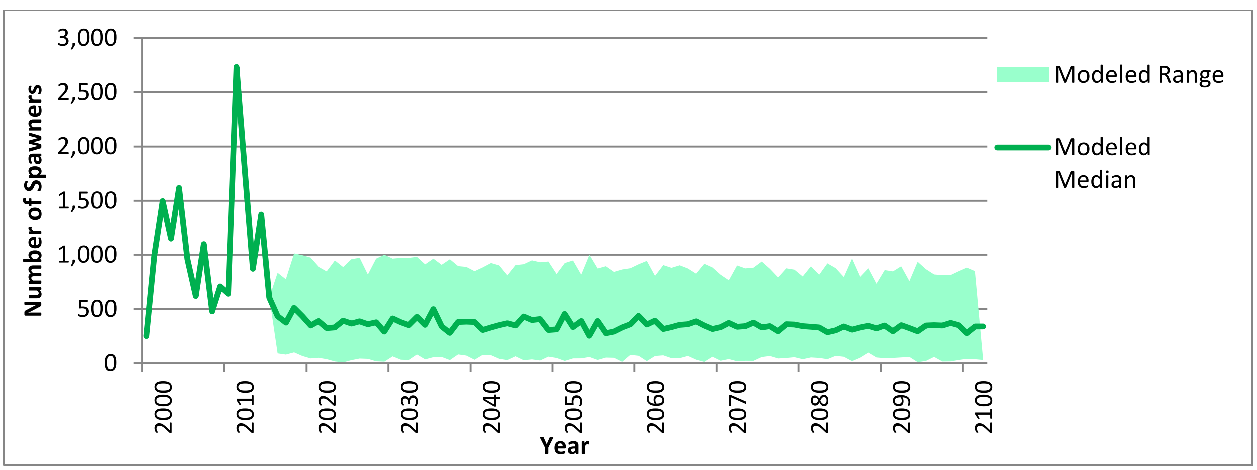
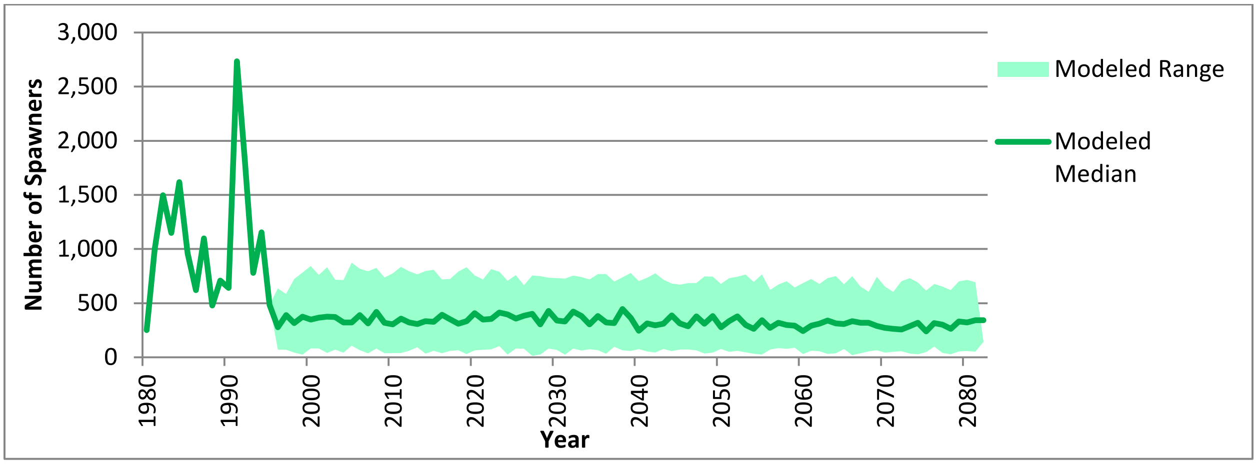
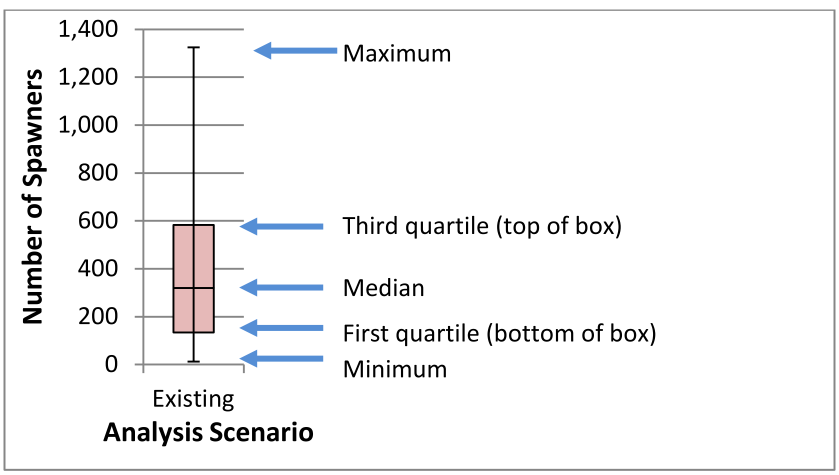


Figure 4.13
Estimated Number of Coho Salmon Spawners with the Multi-Purpose Dam



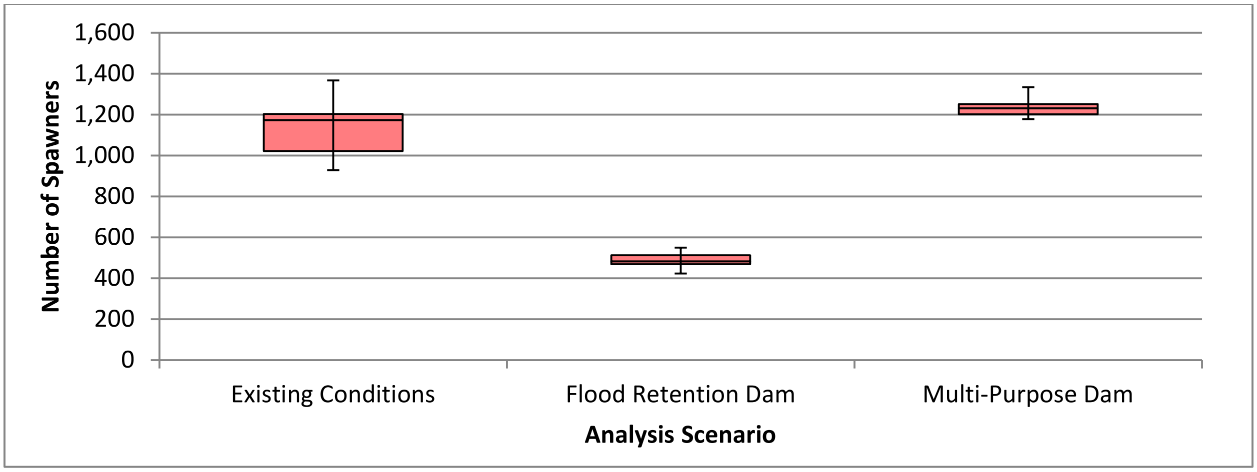
To characterize the overall relative differences between the modeled effects of the different dam alternatives on each salmonid species, the distribution of the predicted number of spawners throughout the simulation period was determined. For the purposes of presenting a comparison among all alternatives analyzed, the results are presented as the predicted minimum, first quartile, second quartile (median), third quartile, and maximum results. These results are presented in a box-plot figure, as shown in Figure 4.14.

Figure 4.14
Example of Box Plot Figure Used to Present Variability of Spawner Number Estimates in SHIRAZ Simulations



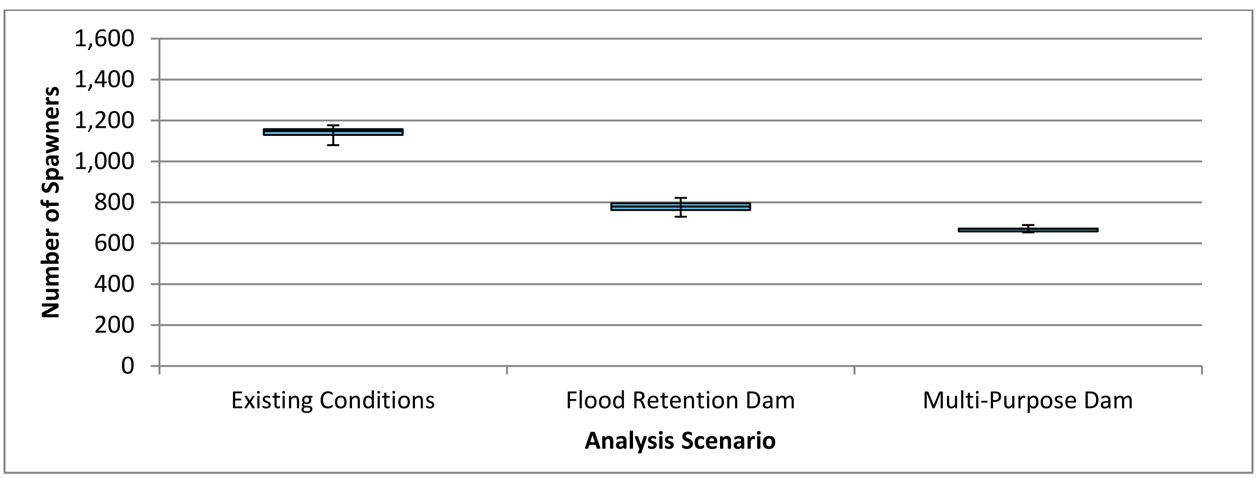
For spring-run Chinook salmon, the estimated median number of spawners decreased by 59% under the FRO Alternative compared to the existing conditions scenario in years 2090 to 2099 (Figure 4.15). In contrast, there was an estimated increase of 5% in the MPD Alternative compared to existing conditions. The range of estimated number of spawners was greatest in the existing conditions scenario. The existing conditions range encompassed the full range of spawners estimated in the MPD Alternative, indicating that although the estimated median number of spawners was higher with the MPD, the increase was not substantial compared to existing conditions.

Figure 4.15
Comparison of Estimated Median Number of Spring-run Chinook Salmon Spawners by Years 2090 to 2099 (*n*=10) in Existing and Dam Alternatives



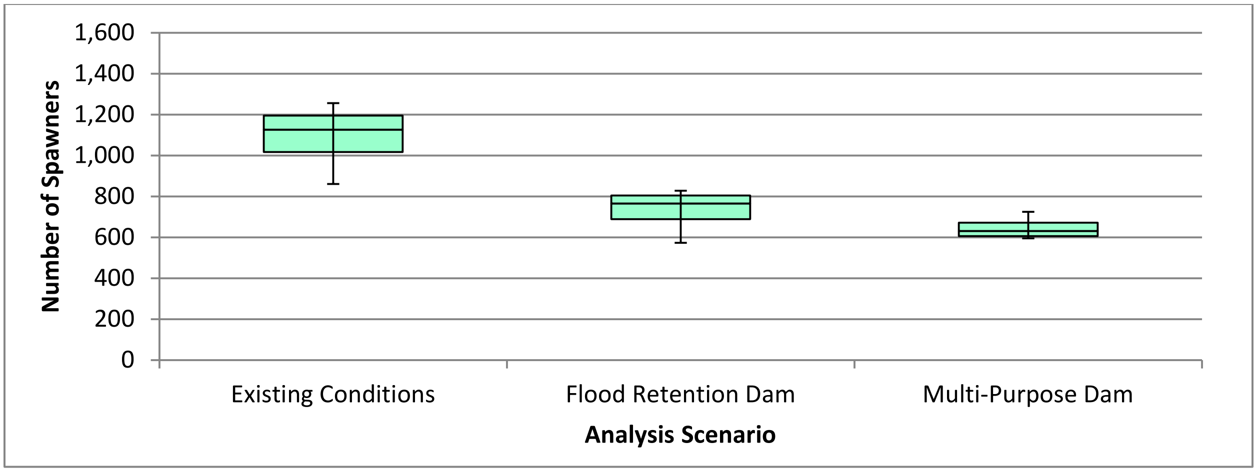
The estimated median number of winter-run steelhead spawners in the 2090 to 2099 period decreased by 32% under the FRO Alternative compared to existing conditions (Figure 4.16). The estimated decrease under the MPD Alternative was slightly greater than the FRO Alternative, and the number of spawners was estimated to decline by 42% compared to the existing conditions scenario.

Figure 4.16
Comparison of Estimated Median Number of Winter-run Steelhead Spawners by 2090 to 2099 (*n*=10) in Existing and Dam Alternatives



The estimated number of coho salmon spawners decreased slightly more under the MPD Alternative than the FRO Alternative (Figure 4.17). The estimated median number of coho salmon spawners in the 2090 to 2099 period decreased by 32% under the FRO Alternative and by 44% under the MPD Alternative. The range of estimated number of spawners was greatest under the existing conditions scenario and decreased considerably in both dam alternatives.

Figure 4.17
Comparison of Estimated Median Number of Coho Salmon Spawners by 2090 to 2099 (*n*=10) in Existing and Dam Alternatives



4.6 Methods: Analyzing Other Fish and Non-fish Species

All fish species depend on the volume and quality of aquatic habitat available to them at various times of year. This volume is sensitive to river hydrology, a key parameter relative to water retention alternatives being considered for the Chehalis River basin. Both the MPD and FRO Alternatives will change the intensity of flood events downstream, which translates into changes in inundation of in-channel, floodplain, and off-channel habitats. In-channel habitats that may be affected by changes in inundation include the main river or stream channel and side channels that are connected to the main channel. Off-channel habitats that may be affected include oxbows and seasonally inundated waterbodies. Species that occupy these habitats at any life stage could be affected by such changes in both the magnitude and period of inundation. Changes in geomorphic processes can also occur that may affect habitat availability, such as channel migration rates and possibly channel formation.

Two methods were used to evaluate the amount of habitat available to Other Fish and Non-fish Species under baseline conditions and with water retention alternatives. These addressed the two major types of habitat potentially affected by Flood Retention Alternatives: in-channel (including side channels) and off-channel. The first method was PHABSIM, a tool used extensively for modeling fish habitat response to hydrology and hydrological modification (Bovee et al. 1998). The goal of this analysis was to establish baseline conditions of in-channel weighted usable area (WUA) for various species under normal WY conditions as represented by HEC-RAS model outputs and how WUA changed under water retention alternatives.

The second method used was correlative models. The goal of this analysis was to quantify the amount of off-channel habitat located in the floodplain that is currently present under various flood events under both baseline conditions and with water retention alternatives. For those species where data were sufficient to support it, both PHABSIM modeling of in-channel habitat and correlative modeling of off-channel habitat area were conducted.

4.6.1 IN-CHANNEL HABITAT

4.6.1.1 BASELINE CONDITIONS

PHABSIM studies predict stream depth and current velocity distributions in relation to streambed features (bed material and cover objects). The model then compares the co-distribution of stream depth, velocity, and substrate or cover to calculate an index of habitat quality and quantity. This produces an estimate of WUA. HSIs are the standards for each life stage and species, rating different stream depths, velocities, and substrates in regard to their habitat value on a scale of 0 (not preferred) to 1.0 (most preferred). If depth, velocity, and substrate are each in the preferred range of a given species at a particular flow, then the cell (a rectangle of stream bed and the water flowing over it) is rated as having a suitability of 1 (1x1x1), which is a multiplier for the area of the cell. All cells were added together at each flow modeled to generate WUA, which is measured as square feet of WUA per 1,000 feet of stream channel length.

Previously defined HSIs available for selected Key Species were used to analyze effects on Pacific lamprey, chum salmon, smallmouth bass, and largemouth bass. Largescale sucker, speckled dace, and western toad lacked previously defined HSIs useful for these analyses, but the requisite data for these species was accessed from literature to generate useable HSIs. Further, white sturgeon had a previously developed HSI, but it is specific to spawning and rearing (Parsley and Beckman 1994). As no known spawning or rearing white sturgeon populations exist in the Chehalis River and the white sturgeon present enter the system as adults, white sturgeon were not modeled using PHABSIM. However, information about adult white sturgeon habitat preferences is provided in the following paragraphs.

Normandeau Associates conducted PHABSIM studies in 2010 to model Chehalis River basin depth and velocity distributions at various flow levels and sites selected to be representative of different reaches (Normandeau Associates 2012a, 2012b). Reaches covered by these PHABSIM studies included the following:

- Near the proposed dam site to Pe Ell (RM 116 to 111.8; RKm 186.6 to RKm 179.5)
- Pe Ell to Elk Creek (RM 111.8 to 105.0; RKm 179.5 to 169.6)
- Elk Creek to the South Fork Chehalis River (RM 105.0 to 92.8; RKm 169.6 to 149.1)
- South Fork Chehalis River to the Newaukum River (RM 92.8 to 78.4; RKm 149.1 to 125.9)
- Newaukum River to Skookumchuck River (RM 78.4 to 69.2; RKm 125.9 to 111.2)
- Skookumchuck River to Porter Creek (RM 69.2 to 35.7; RKm 111.2 to 57.3)

The biological data used during the PHABSIM modeling was collected during WDFW's riverscape survey conducted in 2013. Therefore, the RM values used are based on WDFW's delineations of river kilometers developed for their surveys from analysis of aerial photographs taken in 2011. The RM location of the proposed dam site for the upstream-most end of the PHABSIM reach used here is 110.9 (RKm 178.5; Caldwell et al. 2004). The difference between the dam location in the WDFW riverscape survey and the current dam site noted in the Chehalis basin Flood Study likely reflects a combination of resolution, changes in river position, and fractal considerations. For the riverscape survey, WDFW used the centerline of the channel starting at the Highway 101 Bridge in Aberdeen, Washington, and followed the river's current path, which included changes in channel structure due to post-2007-flood channel migration.

Variable ranges of flows were modeled for the different reaches, which reflected downstream flow accumulation. For some of the sites, two hydraulic models were available: one based on velocities at the highest calibration flow measured and one based on the velocities at the lowest calibration flow measured. When required, these two models were integrated to give one overall WUA for different species at different life stages. The primary function of PHABSIM is to identify the sensitivity of species to changes in stream flow, particularly during more active stages of life history (i.e., summer when cold-blooded organisms have higher metabolic rates). For this reason, high flows occurring primarily during winter months are frequently outside of the calibration range of PHABSIM.

Note that several species of salmon were modeled using PHABSIM, including those addressed using EDT and SHIRAZ. Coho salmon, Chinook salmon, and winter-run steelhead were modeled to evaluate how changes in flow associated with MPD Alternative operations affected salmon and steelhead habitat based on PHABSIM, and to provide results that could be compared to results for related species. Also, note that PHABSIM evaluates changes in area related to changes in flow; it does not reflect changes in substrate associated with increased flows.

When possible, WUA for Other Fish Species were compared with other previously determined WUAs for species that have HSIs developed specifically for PHABSIM (Chinook salmon, coho salmon, steelhead, and mountain whitefish [*Prosopium williamsoni*]). Additionally, habitat suitability criteria for steelhead have been validated (Beecher et al. 1993; 1995). As some species' life histories do not include all reaches modeled by PHABSIM, species were modeled only for reaches where they would be present during at least one life stage.

4.6.1.2 WATER RETENTION ALTERNATIVES

Estimates of WUA of in-channel habitat under dam alternatives were developed using methods similar to those described upstream from and used to estimate baseline conditions. For these analyses, operations of the FRO Alternative and baseline conditions were considered to be similar with regards to hydrology during the low flow summer months when fish are most active and habitat is most likely to be limiting. Therefore, only a comparison of baseline conditions to the MPD Alternative was conducted.

Estimates of WUA produced by PHABSIM were compared three ways: 1) flows that maximize WUA were compared to median monthly flows for a Normal WY to see when and where flows may be limiting WUA; 2) monthly WUA for spawning and rearing for the baseline flows were compared to those associated with the proposed MPD Alternative; and 3) overall, seasonally weighted WUA index values for each species were generated so that rearing WUA and spawning WUA were incorporated into a single index with weightings for each component to compare overall yearly scenarios for the baseline and MPD Alternative.

For the first method of analysis, the flow that maximized WUA for each species and each life stage were identified and reported in Appendix A, Tables A-3 through A-10.

For the second method of analysis, WUA for spawning and/or rearing for species of interest at monthly median flows for WY 2008 were compared as a reasonable first estimate of effects of flow modification. Although WY 2008 included the record flood of December 2007, the total flow for the WY was within the average range. Because habitat effects are typically chronic (lasting weeks rather than hours or days) and the organisms being considered are poikilotherms (cold-blooded), habitat availability during spring, summer, and fall is most likely to be limiting to these animals, and a median flow during those seasons is likely to reflect the effects of changing hydrological regime on the animals and their habitat. These monthly comparisons are shown in Appendix A, Tables A-11 through A-18.

For the third method of comparison that generated a single WUA index value for Other Fish species and western toad analyzed with PHABSIM, rearing WUA and spawning WUA were incorporated into a single index with weightings for each component (see Table 4.7). For this analysis, monthly rearing WUA values were weighted based on approximate monthly water temperature as it is assumed WUA is more important during warmer months when cold-blooded vertebrates are more active. Thus, monthly weighting factors were 1 for December through February, 2 for March and November, 3 for April, 4 for May and October, 5 for June, and 6 for July through September. All 12 weighted rearing months were added together. This weighting of monthly rearing WUA values highlights the fact that higher metabolic rates presumably drive these cold-blooded vertebrates to need more habitat per individual as they become more active, have higher food requirements, and related higher territoriality. This does not account for a Habitat Temperature Index, which is also based on activity levels as a function of temperature and reduces WUA at higher temperatures. Because of this, more uncertainty exists about how these two ways of considering temperature-influenced WUA reflect actual biological survival and productivity. For spawning WUA values, the temperature-based weighting was not used because spawning is generally season-specific.

Next, the sum of spawning WUA for all months where it would occur was added together and multiplied by 41/x, where *x* is the sum of spawning months' weighting factors. The spawning multiplier accounts for the non-spawning months. Spawning WUA values in any month may be considerably higher than the temperature-weighted rearing values, so the contribution of spawning and rearing to the combined flow-habitat index are not necessarily equal or even close. Both the sum of the spawning WUA and rearing WUA were totaled to obtain a single WUA value for each of the species analyzed by PHABSIM.

To compare the baseline to MPD WUAs for the second and third methods, values for the MPD were divided by those for the baseline condition. A resultant ratio greater than 1.0 indicated increased WUA under the MPD Alternative relative to the baseline; a ratio below 1.0 indicated decreased WUA. These changes were then reported as percent change to the nearest 1 percent (e.g., 1.07635 is reported in tables as +8%). As different reaches responded differently, a reach-weighted average of the ratios was calculated for each month for the second method, and each year for the third method.

Two salmonids were addressed in this comparison: mountain whitefish and chum salmon. Although mountain whitefish are not Key Species, they were modeled because they co-occur in mixed schools with largescale suckers and they represent a good surrogate for largescale suckers because more in-stream flow modeling has been conducted on mountain whitefish. The PHABSIM model characterizes mountain whitefish habitat better than sucker habitat, particularly for rearing. The in-stream flow modeling is typically based on mean water column current velocity, whereas information on the suckers generally focuses on the water velocity near the streambed. Finally, mountain whitefish were modeled because they often have the greatest fish biomass in most medium-to-large streams in Washington State. One notable difference between the species, however, is that largescale suckers spawn in the spring and whitefish spawn in the fall.

Chum salmon were not included in EDT or SHIRAZ and were therefore modeled using these methods. They use downstream reaches of the Chehalis River basin including tributaries up to Scatter Creek for spawning in late fall. Their eggs incubate through winter and chum salmon contribute large quantities of marine-derived nutrients to stream and river ecosystem when they die after spawning.

4.6.2 OFF-CHANNEL HABITAT

4.6.2.1 BASELINE CONDITIONS

For Other Fish and Non-fish Species, a baseline area of inundation was mapped using HEC-RAS model outputs and RASMapper water depth raster surfaces with a resolution of 12 feet by 12 feet. This was done for 500-year, 100-year, 20-year, 10-year, and 2-year flood events. A 0.1-foot water depth threshold was used in calculating the inundated area, that is, water depth had to exceed 0.1 foot to be considered inundated. This was to eliminate insignificant wetting at the fringes of the floodplain due to the inherent precision of the hydrologic models. The river was divided into 10 segments of varying length that had breakpoints based on inputs from major tributaries (Figure 4.2).

The correlative modeling applied to the entire suite of species that occupy off-channel habitats, which includes amphibians, western pond turtle (*Clemmys marmorata*), North American beaver, and selected fishes. For selected fishes, all of which were in the Other Fish group, this included Pacific lamprey juveniles, Olympic mudminnow (all life stages), speckled dace, largescale sucker juveniles, riffle sculpin, reticulate sculpin, and largemouth bass. For Non-Fish Species, this included three key amphibian species (northern red-legged frog, and Oregon spotted frog, and western toad), the western pond turtle and North American beaver.

4.6.2.2 WATER RETENTION ALTERNATIVES

Inundation areas estimated for the between dam and no-dam scenarios using HEC-RAS and RASMapper water depth raster surfaces as discussed upstream from under the baseline conditions were compared. Different dam alternatives (i.e., FRO versus the MPD Alternative) were not compared. This is because both types of dam were assumed to have a maximum flow of 10,000 cfs (283 m^3/sec) under flooding conditions and during flood events, flow through both dams could only increase to a maximum of 10,000 cfs (283 m^3/sec). Therefore, the results of analyses are reported as differences between a generic dam and the no-dam condition.

Inundation areas were calculated for the same 10 segments of the river used in the baseline conditions (Figure 4.2). The percent change in inundation area was calculated as an index:

$$I_t = ((A_t - A_{tdam})/A_t) * 100$$

Where:
I_t = inundation index at flood size t (t = 2-year, 10-year, 20-year, 100-year, or 500-year flood event)
A_t is the acres inundated at flood size t with no dam.
A_{tdam} is the acres inundated at flood size t with a dam.

The index (I_t) is a measure of the percent change in areas inundated with and without a dam across a range of flood events.

The index provided an approximate measure of change in acres that could be inundated at that flood level given that land surface elevation. The index did not address changes in the connectivity of off-channel habitat to the mainstem, the spatial extent of water in the floodplain, or the length of time of an area was inundated.

4.7 Results: Other Fish and Non-fish Species

4.7.1 IN-CHANNEL HABITAT

Estimated WUA values from PHABSIM model studies are presented in Appendix A, Tables A-3 through A-10. Flows were compared to median monthly flows obtained from HEC-RAS model output from locations noted in each table. Values represent median flow that maximized WUA for each life stages and species by month. Median monthly flows for each reach were obtained from HEC-RAS daily flows modeled for comparable cross sections of the Chehalis River for 12 months of a normal WY (WY 2008). WUAs were presented in the months that were most applicable to a species for that life stage and require validation if future analyses of flow-habitat relationships are conducted in subsequent phases of the Project. WUA is a better index of too little flow than of too much flow. Therefore, conditions of too little flow were identified by underlining values in the tables in Appendix A where median flows were lower than flows that maximized WUA for a life stage or species. For these months, increased flows could potentially increase or maximize WUA for the life stage or species. For example, in the upper Chehalis River reach, Pacific lamprey spawning in May and June is limited by the median monthly flows being lower than what is required to maximize WUA during this time period (Appendix A, Table A-3).

4.7.1.1 BASELINE CONDITIONS BY REACH

4.7.1.1.1 Upper Chehalis River

The uppermost PHABSIM reach has a high gradient and numerous pool and side-channel habitats and is used primarily by salmonids. During the WDFW riverscape survey in 2013, adult Chinook salmon, juvenile salmon, and steelhead were observed. These species are known to spawn and rear in this reach. Additionally, western toad, Pacific lamprey, speckled dace, mountain whitefish, and largescale sucker are present in this reach.

For Pacific lamprey spawning, steelhead rearing, western toad, coho salmon, and mountain whitefish spawning and rearing, median monthly flows were lower than flows that maximize the fishes' habitat (or WUA; Appendix A, Table A-3). This strongly suggests that summer and early fall low flows are a limiting factor in the upper Chehalis River reach and that flow reductions in summer and early fall could be detrimental to these species. Beecher et al. (2010) also reported the limiting effect of low summer and early fall flows on coho salmon in the Chehalis basin.

4.7.1.1.2 Pe Ell to Elk Creek

The river between the mouth of Elk Creek and Pe Ell, Washington is wider and flatter than the previous reach, but still has a clearly evident gradient. Similar to the upper Chehalis reach, flows available for Pacific lamprey spawning, coho and Chinook salmon, steelhead, and mountain whitefish spawning and rearing were lower than what is required to maximize WUA (Appendix Table A-4). This suggests that increasing flow from April through November could potentially increase WUA for these species.

4.7.1.1.3 Elk Creek to South Fork Chehalis River

This reach has lower gradient than the two previous reaches. It is warmer and was used less by salmonids according to the WDFW riverscape survey conducted in 2013, which also confirmed the presence of adult and juvenile dace as well as adult and juvenile largescale suckers in the reach. In general, estimated WUA was highest for most non-salmonid species (15,000 to 50,000 feet^2/1,000 feet along the longitudinal gradient) in the reach. Also, for Chinook and coho salmon, steelhead, and mountain whitefish, WUA was maximized at flows greater than the median monthly flows modeled under normal WY conditions, suggesting flow is limiting these species during summer, fall, and in some cases, winter (Appendix A, Table A-5).

4.7.1.1.4 South Fork Chehalis River to Newaukum River

The gradient of the river in this reach continues to decrease and wetted width of the channel increases when proceeding downstream. Salmonid use is minimal in this and the adjacent downstream reach and bass presence increases. Pacific lamprey, largescale sucker, mountain whitefish, Chinook and coho salmon, and steelhead had WUA limited by flow compared the median monthly flows modeled for the normal WY (Appendix Table A-6). As salmonid use of habitat in the reach is minimal, these flow limitations were considered to be most applicable to Pacific lamprey and largescale sucker spawning from April to June.

4.7.1.1.5 Newaukum River to Skookumchuck River

This reach is similar to the previous reach in that it has low gradient and warmer temperatures. The presence of largemouth bass in this reach is significantly higher than reaches upstream of the confluence with the South

Fork Chehalis River. Of the species considered, all except largemouth bass had WUA maximized at flows higher than the comparable median monthly flows calculated for this reach (Appendix Table A-7). All salmonid WUA was limited by flow for all of the months considered. Similar to the previous reach, salmonid use of this part of the river is considered minimal. Pacific lamprey spawning WUA was limited by flow during spring and summer months, as was smallmouth bass rearing. Largescale sucker spawning and rearing WUA was also limited by flow for the spring and summer months.

4.7.1.1.6 Skookumchuck River to Porter Creek

Low gradient and warm water temperatures characterize this lower reach, similar to the next two upstream reaches. Similar habitat characteristics are present as well. However, one difference is that chum salmon spawning occurs in this reach. Species and life stages in this reach where flows are limiting WUA are Pacific lamprey (spawning during spring), Chinook salmon (spawning and rearing during summer and fall), steelhead rearing during summer and fall, coho rearing salmon during fall, and mountain whitefish rearing during spring, summer and fall (Appendix A, Table A-8).

4.7.1.2 BASELINE CONDITIONS BY SPECIES

4.7.1.2.1 Pacific Lamprey

Pacific lamprey spawning habitat was generally maximized at a higher flow (middle of the range modeled), although in the upper Chehalis River Pacific lamprey spawning habitat was maximized at the highest flow modeled (350 cfs [9.9 m^3/sec]). In contrast, rearing flow was maximized at the lowest flow modeled in all reaches.

4.7.1.2.2 Largemouth Bass

Excluding the upper Chehalis reach, spawning and rearing were maximized at the lowest flows for largemouth bass. This reflects their habitat preferences for backwater and low flow areas and suggests that flow augmentation would not be favorable to largemouth bass. However, higher flows would inundate some side-channel areas and would potentially create habitat for largemouth bass; the level at which higher flows might create habitat and how much habitat was created was not addressed. The upper Chehalis reach includes boulders, bedrock, and cascade, which are not preferred habitat by largemouth bass.

4.7.1.2.3 Smallmouth Bass

At most sites, smallmouth bass WUA peaked at low flows. However, these flows were consistently higher than flows where WUA for largemouth bass peaked. Smallmouth bass WUA also peaked at considerably lower flows than did WUA for salmonids at sites. This is consistent with smallmouth bass preferring faster water and being a more lotic-adapted (i.e., flowing water) species compared to stillwater conditions largemouth bass prefer.

4.7.1.2.4 Speckled Dace

Over most reaches, speckled dace WUA was maximized at lower, intermediate flows. Exceptions to this pattern were between Elk Creek and Newaukum River and at the downstream-most reach (Skookumchuck River to Porter Creek) where dace WUA peaked at the lowest flows modeled.

4.7.1.2.5 Largescale Sucker and Mountain Whitefish

Largescale sucker WUA generally peaked at lower, intermediate flows. For juvenile rearing, low flows resulted in greater WUA, which is related to juveniles rearing in side-channel areas. However, for adult spawning, higher flows were expected to have produced larger WUAs. Previously established mountain whitefish WUAs were compared to the PHABSIM results for largescale sucker (Appendix A, Table A-9) because adults of the two species tend to school together and therefore should have similar flow preferences, which was not reflected in these results. Also, the previous estimates of WUA for mountain whitefish were based on HSIs developed specifically for PHABSIM using mean water column current velocity. Because the previously estimated WUA was maximized for mountain whitefish at higher flows, flow preferences that maximize WUA for largescale sucker in the current analysis were assumed underestimate this species' actual flow preferences; however, this requires validation.

4.7.1.2.6 Salmonids

Chum salmon were modeled in the downstream-most reach (Skookumchuck River to Porter Creek) only, which reflects the uppermost extent of their distribution in the Chehalis River basin. Chum salmon adults migrate upstream beginning in October and spawn during fall, with fry migrating to sea immediately after emergence in spring. The modeled flows that produced the largest amount of WUA for chum salmon peaked at the second to lowest flow modeled whereas Chinook and coho salmon and steelhead WUA generally peaked at medium to medium-high flows (Appendix A, Table A-10). This agrees with the required spawning conditions for these species.

4.7.1.2.7 Western Toad

PHABSIM modeling indicated that at all sites other than the upper Chehalis River (where calibration data were gathered in the inundation footprint), WUA was maximized at the lowest flow modeled. This reflects the western toad's preference for shallow, slow water.

Modeling for the toad was restricted to reaches upstream from the Elk Creek to South Fork Chehalis River reach because western toads were recorded exclusively in this part of the Chehalis River main channel during WDFW's 2013 riverscape surveys. However, this may underestimate toad distribution in the main channel because downstream efforts in WDFW's riverscape surveys were interrupted by the onset of increased flows in the fall of 2013, and the 2014 surveys did not extend below the South Fork. Western toad modeling was restricted to the June to October period when toad life stages were anticipated to be present in the in-stream macrohabitat. Lastly, caution should be used in interpreting PHABSIM results for western toad because in some cases, the cross-stream transects used to set gage velocities values did not extend into the isolated portions of the channel, which are key toad habitats. This reflects a very preliminary effort to model toad habitat with information originally designed to address fish habitat.

4.7.1.3 SEASONALLY WEIGHTED, WEIGHTED USABLE AREA CHANGES FROM BASELINE TO PROPOSED MULTI-PURPOSE DAM FLOWS

Table 4.7 shows the percent change in habitat, expressed as overall seasonally weighted WUA yearly values for each species modeled using PHABSIM, when flow releases under the MPD Alternative are compared to baseline flow releases. Because mean monthly flows were generally unaffected by the FRO Alternative, WUA was unchanged from baseline conditions under this alternative. Also, the PHABSIM model was not calibrated in the range of the peak flows that would be modified by the FRO Alternative. Therefore, no analysis was performed for the FRO Alternative.

Table 4.7
Hydraulic Habitat (WUA) Weighted for Seasonal Changes in Habitat and the Percent Change from Baseline Compared to Multi-purpose Dam Alternative Flow Release

SPECIES	PE ELL TO ELK CREEK	ELK CREEK TO SOUTH FORK	SOUTH FORK TO NEWAUKUM	NEWAUKUM TO SKOOKUMCHUCK	SKOOKUMCHUCK TO PORTER
Pacific lamprey	+9%	+2%	-2%	+1%	-1%
Largemouth bass	NA	-9%	-15%	-2%	-5%
Smallmouth bass	NA	-10%	-10%	0%	-3%
Speckled dace - rearing only	-9%	-6%	-6%	+3%	-3%
Largescale sucker	-16%	-11%	-5%	+1%	-3%
Mountain whitefish	+13%	+10%	+8%	+12%	+3%
Chum salmon	NA	NA	NA	NA	+1%
Western toad – rearing only	-5%	-6%	NA	NA	NA

Note:
NA = not applicable; indicates the species was not recorded in that reach at any life stage.

Results of the seasonally weighted changes in WUA under the MPD Alternative compared to the baseline (no-dam) condition for in-channel habitat for each Other Fish and Non-fish Species modeled are described in the following paragraphs.

4.7.1.3.1 Pacific Lamprey

Pacific lamprey seasonally weighted WUA increased slightly in the Pe Ell to Elk Creek reach, the Elk Creek to South Fork Chehalis River reach, and the Newaukum River to Skookumchuck River reach. There were slight decreases in the South Fork Chehalis River to Newaukum River reach and the Skookumchuck River to Porter Creek reach (Table 4.7). These overall changes in seasonally weighted WUA reflect changes during warmer and dryer months in which lamprey spawn as well as the cooler, wetter months which include rearing.

Monthly changes in WUA included both increases and decreases for spawning and rearing for each reach. Generally there were increases in spawning WUA occurred during the summer months, which likely reflects increased flows from the proposed MPD in the low flow months (Appendix A, Table A-11). The increases ranged from less than 1% in April to 10% in May and nearly as much in June. Results varied greatly by reach, with spawning WUA increasing up to nearly 20% in reaches upstream from the Newaukum River confluence and being minimal in reaches located lower in the system. This longitudinal trend correlates to the more negligible effect on flows the further downstream from the water retention facility.

In contrast, Pacific lamprey rearing WUA habitat decreased during the warmer, lower-flow months under the MPD operations (Appendix A, Table A-11). The greatest decreases during this period were in the Elk Creek to South Fork reach, with WUA declining as much as 29% during May, reflecting the greatest increase in flow for this month. The months with significant increases in lamprey rearing WUA were November and December, which corresponds to decreases in median monthly flows under the MPD Alternative. In the Newaukum to Skookumchuck reach, WUA increased slightly during this period.

4.7.1.3.2 Largemouth and Smallmouth Bass

For largemouth bass, seasonally weighted WUA decreased from 2 to 15% under the MPD Alternative (Table 4.7). The greatest decrease was in the South Fork Chehalis River to the Newaukum River reach. Largemouth bass spawning WUA decreased relative to baseline conditions by 12 to 15% between May and August in response to increased flows from the MPD Alternative (Appendix Table A-12). The greatest decreases (28 to 37%) occurred in the South Fork to Newaukum reach, likely due to this being the upper extent of largemouth bass range in the Chehalis system. Largemouth bass rearing habitat also decreased from 9 to 12% during the warm, lower flow summer months between May and August in response to increased flows released by the MPD Alternative during the summer months.

For smallmouth bass, seasonally weighted WUA generally decreased in all reaches where smallmouth bass are known to occur (Table 4.7). The greatest decreases were in the two uppermost reaches (Elk Creek to South Fork Chehalis River and South Fork Chehalis River to the Newaukum River) at 10% each. No change was shown for the Newaukum River to Skookumchuck River reach, but a -3% change was found for the Skookumchuck River to Porter Creek reach. Smallmouth bass spawning habitat decreased by 2 to 13% during spring and summer months, with the largest decrease occurring in May, also due to increased flows (Appendix A, Table A-12). The two reaches with the largest decreases were Pe Ell to Elk Creek (up to 50%) and South Fork to Newaukum (up to 15%). Smallmouth bass rearing WUA decreased by up to 14% in May, while lesser decreases (1 to 12%) were observed in other spring and summer months. This corresponds with the greatest increases in median monthly flows being in May as well as decreases to a lesser extent in other summer months. Smallmouth bass rearing WUA decreased by up to 14% in May while lesser decreases (1 to 12%) were seen in other spring and summer months under the MPD flows.

4.7.1.3.3 Speckled Dace

Seasonally weighted WUA associated with MPD operations decreased from 3 to 9% in all reaches except the Newaukum River to Skookumchuck River reach, which showed an increase of 3% (Table 4.7). Changes in dace spawning habitat were not assessed due to a lack of information needed to develop habitat suitability preferences.

Speckled dace rearing habitat declined by 1 to 10% during April through September under the MPD operations, with May having the greatest decline (Appendix A, Table A-14). These changes in WUA reflect the altered flows proposed under the MPD's operations, which included increased median monthly flows from May through September. Among reaches, declines in the South Fork to Newaukum reach were slightly greater than in the two reaches between this reach and the proposed dam site. In the reach between the Newaukum and Skookumchuck, speckled dace rearing habitat increased under the MPD operations.

4.7.1.3.4 Largescale Sucker and Mountain Whitefish

Seasonally weighted WUA decreased for largescale sucker in all reaches except the Newaukum River to Skookumchuck River reach. Decreases were greatest from Pe Ell to Elk Creek at 16% and Elk Creek to South Fork Chehalis River at 11% (Table 4.7). For mountain whitefish, seasonally weighted WUA increased from 3 to 13% and the greatest increase was in the Pe Ell to Elk Creek reach.

Comparing monthly estimates of WUA, MPD operations decreased largescale sucker spawning WUA during March through June by up to 7% (Appendix Table A-15), reflecting the increased median monthly flows proposed by the MPD Alternative. Among reaches, the greatest decrease (up to 28%) was in the Pe Ell to Elk Creek reach. Largescale sucker rearing WUA decreased by up to 15%, with the greatest decrease occurring in May. Among reaches, the reach with the single greatest decrease (37%) was Pe Ell to Elk Creek, followed closely by Elk Creek to South Fork (28%).

Under the MPD operations, monthly WUA for mountain whitefish spawning habitat increased 3% in September and decreased up to 8.5% in the October to December period (Appendix A, Table A-16). This follows increases in flow for September and decreases in October, November, and December. The greatest increases occurred during fall (5%) in Pe Ell to Elk Creek (September and October). Among reaches, the greatest decrease was in the South Fork to Newaukum reach (11% in November). Mountain whitefish rearing WUA increased up to 33% during spring and summer (May) and decreased by up to 12% during winter (January). Mountain whitefish winter activity is demonstrated by a modest winter sport fishery targeting the fish; they actively feed during daylight. Among reaches, the greatest increase was in South Fork to Newaukum reach (70%), followed closely by Newaukum to Skookumchuck reach in July and August (67%).

4.7.1.3.5 Chum Salmon

Chum salmon are only present in one of the reaches analyzed by PHABSIM. Overall, there was a slight increase of 1% in the Skookumchuck River to Porter Creek reach. Monthly comparisons between the MPD Alternative and baseline conditions resulted in little change in chum salmon spawning WUA in the reach downstream from the mouth of the Skookumchuck River to Porter during the fall spawning months (Appendix A, Table A-17).

4.7.1.3.6 Western Toad

Overall, seasonally weighted WUA for western toad decreased by 5 and 6% in the Pe Ell to Elk Creek reach and the Elk Creek to South Fork Chehalis River reach, respectively (Table 4.7). Monthly WUA for western toad under the MPD Alternative declined by up to 9% in June, and were greatest (up to 11.2%) in the Elk to South Fork reach and smallest (up to 7%) in the Pe Ell to Elk Creek reach (Appendix Table A-18). As stated earlier, western toad habitat could not be modeled below the South Fork reach because the WDFW riverscape surveys conducted in 2013 in this area were not completed due high flow and turbidity. Although larval rearing habitat was modeled, spawning habitat requirements are identical and spawning occurs in June.

4.7.1.3.7 In-channel Other Fish and Non-fish Species Response Summary

Except for mountain whitefish and Pacific lamprey, all other species generally showed decreases in habitat under a MPD Alternative. The exception for most species was the Newaukum to Skookumchuck reach, which often showed small increases in habitat for these species. In contrast, mountain whitefish exhibited moderate increases in habitat regardless of reach, and Pacific lamprey displayed some increases, the most pronounced in the Pe Ell to Elk Creek reach nearest the dam.

4.7.2 OFF-CHANNEL HABITAT

4.7.2.1 BASELINE CONDITIONS

The amount (acres) of floodplain inundation in the 10 river segments at different flood intervals is shown in Appendix A, Table A-19. As expected, larger floods produced larger areas of inundation, and the acres inundated generally increased in reaches closer to the mouth of the Chehalis River.

4.7.2.2 CHANGE IN AREA OF FLOODPLAIN INUNDATION BETWEEN DAM AND NO-DAM CONDITIONS UNDER VARIOUS FLOOD EVENTS

A number of consistent patterns are evident in the inundation index across different flood magnitudes. For the most part, the absolute and relative decreases in area of inundation between the no-dam and dam scenarios were greatest for the 500-year flood event (Figure 4.18; Appendix A, Table A-20), though some exceptions to this general pattern existed. For each of the 500-year, 100-year, and 20-year flood events modeled, the reach with the greatest reduction in inundation expressed as percent area change, was from the dam site to Elk Creek, where percent area change was 58%, 51%, and 37%, respectively (Figures 4.18, 4.19, and 4.20; Appendix A, Tables A-20, A-22, and A-23). The one exception was for a 10-year flood, where the largest change occurred in the Elk Creek to South Fork reach, Figure 4.21). Moreover, for all flood scenarios, the magnitude of change was always greatest in the three segments below the dam (i.e., to the Newaukum River), and the inundation index generally decreased with increasing distance downstream of the dam as the effect of the dam is ameliorated by increasing flow from other tributaries. Any variations in this pattern appeared to reflect changes in floodplain topography. For a 2-year flood, the effects of a dam were negligible (Figure 4.22; Appendix A, Table A-21).

Modeling for this effort was conducted based on HEC-RAS, and the modeled inundation patterns represent an index of anticipated changes (not an absolute estimate of areal changes). It should also be noted that hyporheic exchange may connect some of these seemingly disconnected habitats, although the relationship between inundation and hyporheic exchange is unknown.

HEC-RAS is a one-dimensional model that uses discrete transects perpendicular to the Chehalis River across the floodplain to compute water height for a given flood event, interpolates water height between the transects at a 12-foot-by-12-foot resolution, and compares the water height to the surrounding land surface elevation on a cell-by-cell basis regardless of the connection patterns between the river and off-channel habitat. That is, some low lying areas could appear to be inundated based on surface elevation alone, but in reality would not be inundated because flood waters could not reach those areas, due to a dike or raised road bed, for example. To assess how the potential error associated with the approach used to estimate inundation area, WDFW examined the degree to which model-inundated elements of the floodplain were topographically disconnected by converting discrete patches of inundated area to polygons, and establishing whether the polygons intersected the mainstem Chehalis River. All connected patches formed a single polygon. The sum of the area of the disconnected polygons (areas that would not flood) was calculated at different flood magnitudes to determine what proportion area of off-channel areas that did not flood. The disconnected inundated areas represented less than or equal to 3.8% of the total area inundated regardless of the magnitude of the flood. The need for additional studies on this topic are addressed further in the companion *Data Gaps Report*.

Figure 4.18
Floodplain Area Inundated Under Dam and No-dam Scenarios During a 500-Year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam

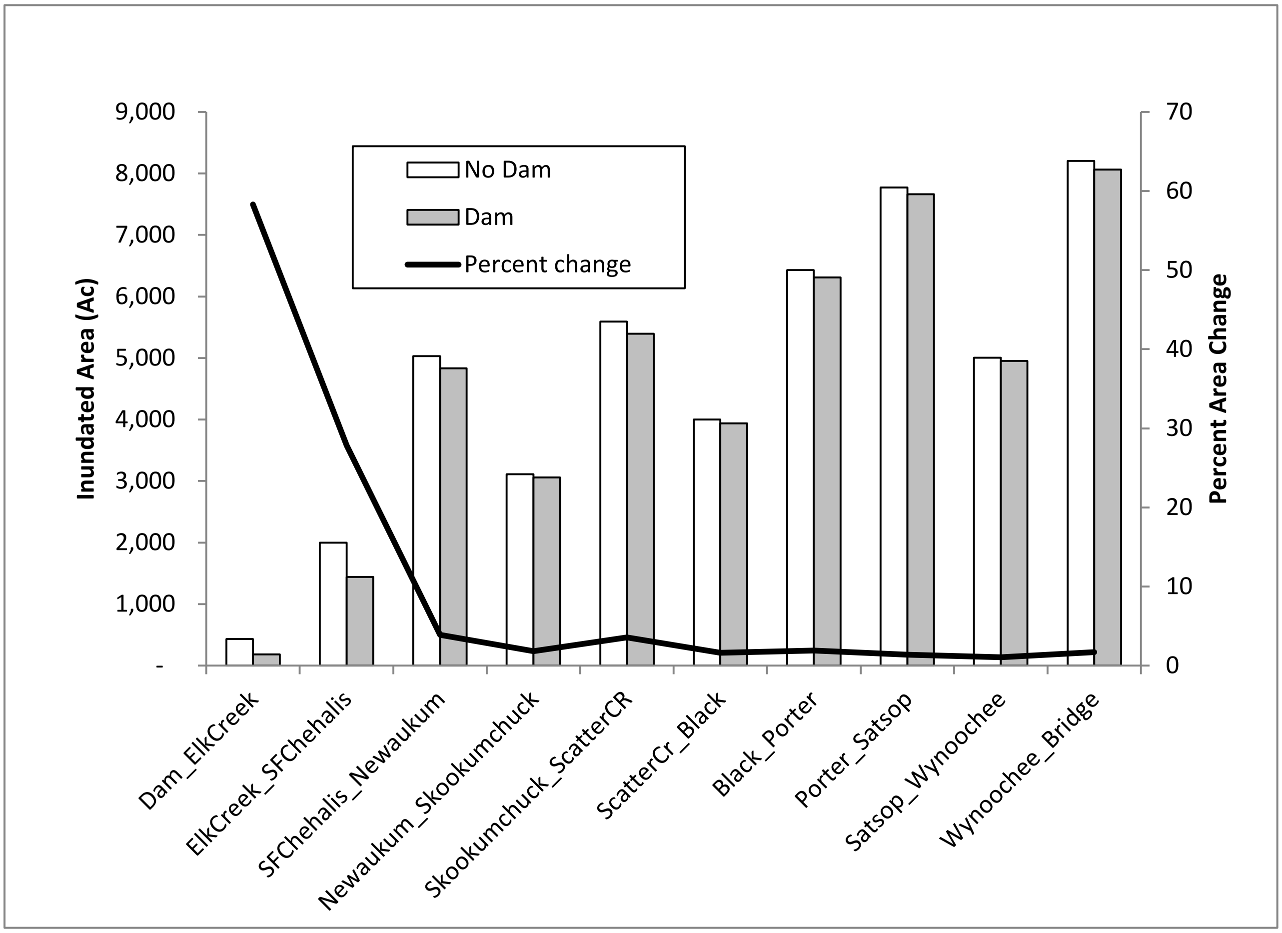


Figure 4.19
Floodplain Area Inundated for Dam and No-dam Scenarios During a 100-year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam

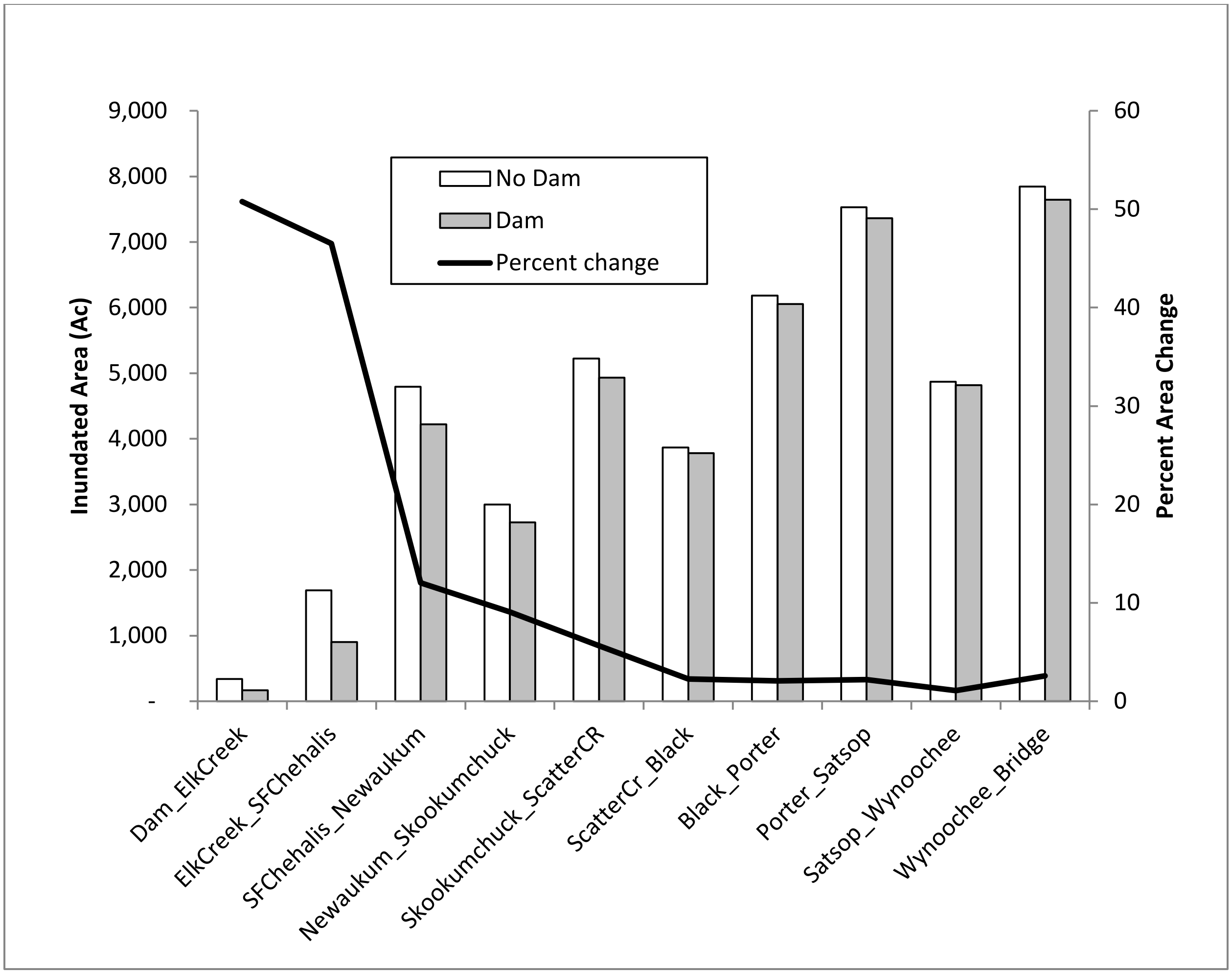


Figure 4.20
Floodplain Area Inundated for Dam and No-dam Scenarios During a 20-year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam

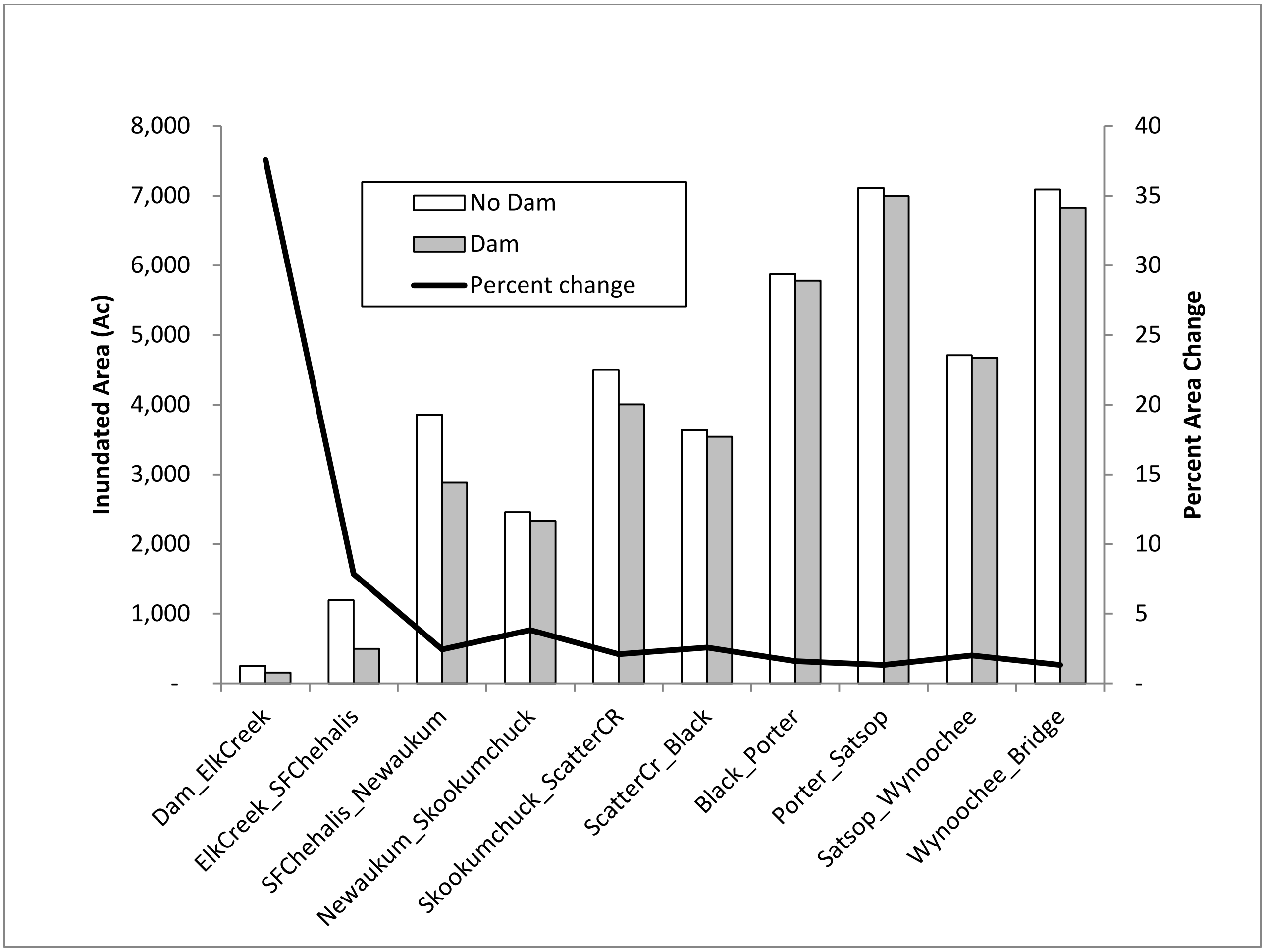


Figure 4.21
Floodplain Area Inundated for Dam and No-dam Scenarios During a 10-year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam

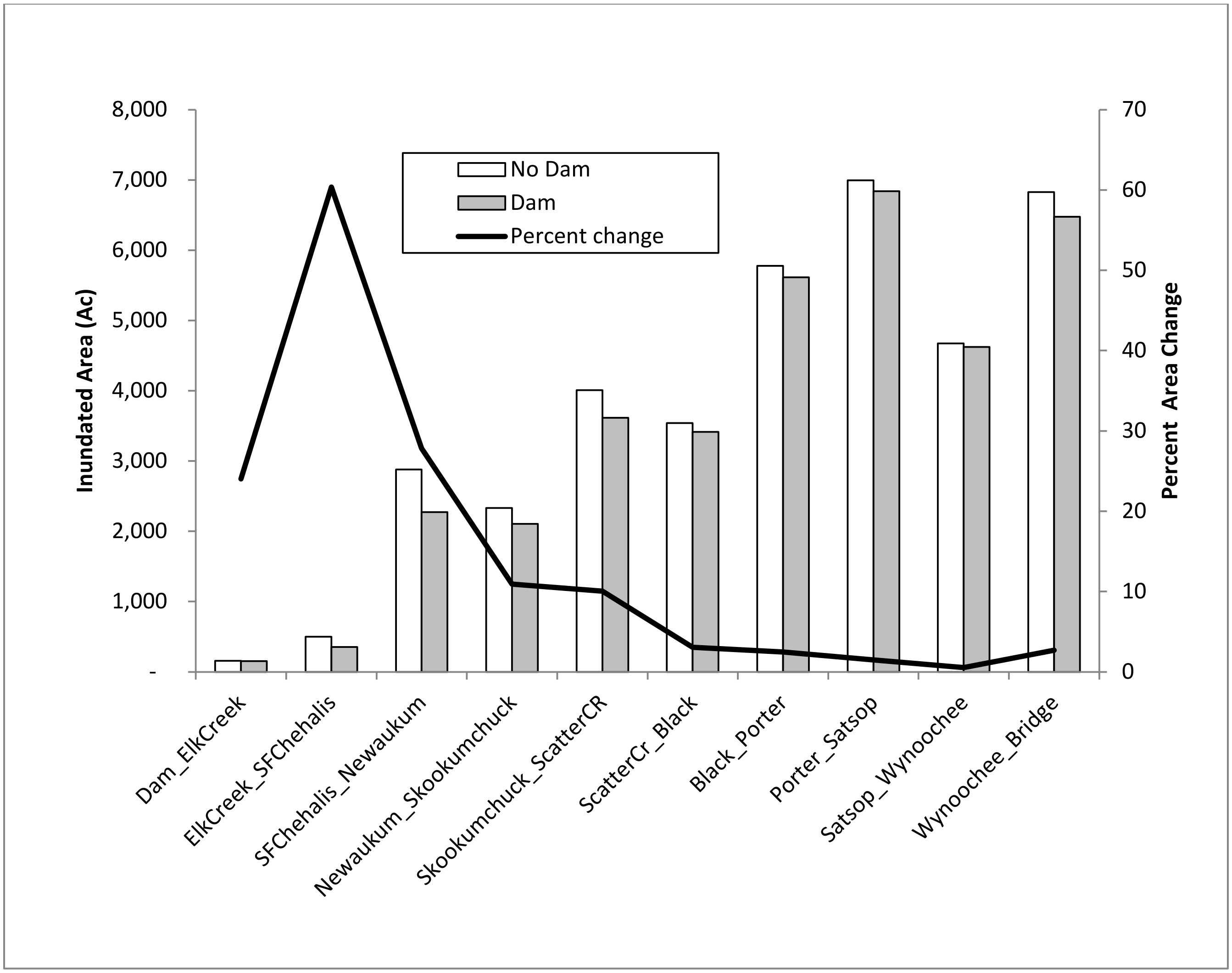
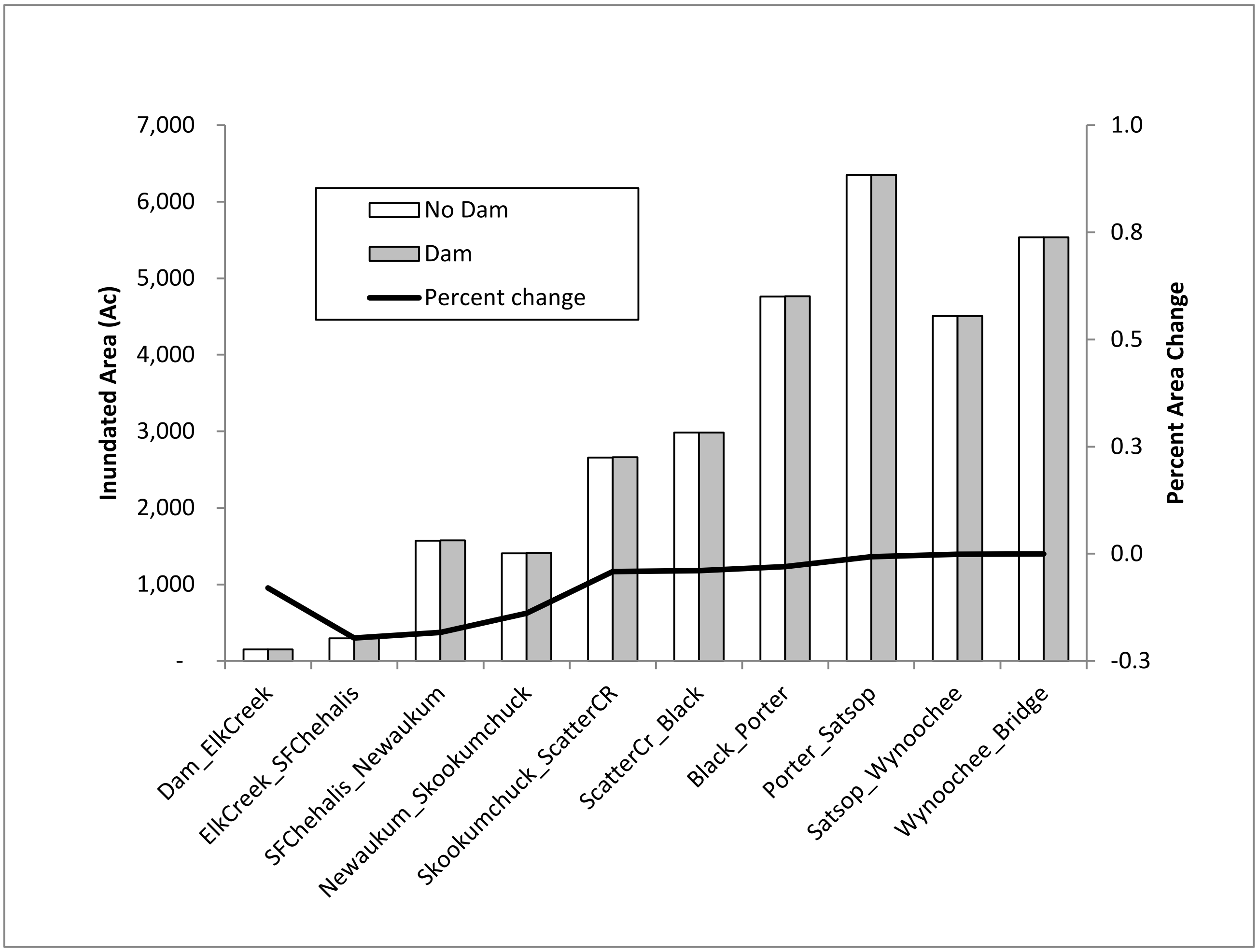


Figure 4.22
Floodplain Area Inundated for Dam and No-dam Scenarios During a 2-year Flood Event and the Inundation Index (Percent Change in Inundated Floodplain Area) With and Without a Dam



Species that occupy off-channel areas in the floodplain depend on the creation and maintenance of off-channel habitat, which evolves in part from inundation due to major flood events (Junk et al. 1989; Trush et al. 2000). Based on this relationship and for the purposes of this phase of analysis, a decrease in inundation was assumed to have a negative effect on the off-channel suite of species, whereas an increase in inundation was assumed to have a positive effect on these species. For Other Fish Species, this included Pacific lamprey juveniles, Olympic mudminnow, speckled dace, largescale sucker juveniles, riffle sculpin, reticulate sculpin, and largemouth bass. For the Non-fish Species, this included three key amphibian species (northern red-legged frog, Oregon spotted frog, and western toad), the western pond turtle and North American beaver.

Modeling the response of species that occupy off-channel areas in the floodplain to a dam alternative using an inundation index was a high-level attempt at evaluating a suite of species for which few data exist. The nature of this modeling disallowed distinguishing responses among species; it could not address issues of connectivity in inundation that are critical in the seasonal dynamic effort of species that utilize off-channel habitats, and it could not address potential impairment of processes that are important in the creation and maintenance of off-channel habitats. These limitations are further described in the companion *Data Gaps Report*.

4.8 Alternatives for Protecting Interstate 5

4.8.1 METHODS

ASEP authors met with Washington Department of Transportation (WSDOT) staff on several occasions during the January to March 2014 time frame. After reviewing four WSDOT alternatives for protecting I-5, it was determined that the following two alternatives may effect aquatic habitat:

- Alternative 1: I-5 walls and levees; raise airport levees; new levees southwest of the city of Chehalis
- Alternative 2: Raise and widen I-5 only

The primary potential effects of these alternatives are changes in water distribution on the floodplain downstream to the Mellen Street Bridge and changes in water supply to areas in the Dillenbaugh Creek watershed below the City of Chehalis.

4.8.2 RESULTS

Any changes in flood inundation patterns associated with the I-5 Alternatives would be difficult to assess for salmon species because changes associated with the I-5 alternatives were expected to have a limited spatial extent (down to Mellen Street Bridge), making it difficult to detect changes at the basin-wide scale. For Other Fish and Non-fish Species, Alternative 1 was anticipated to result in a slight propagation of inundation further downstream with some reduction of that inundation with dam alternatives. In contrast, Alternative 2 was expected to result in no measurable changes in floodplain inundation patterns. To summarize, the I-5 Alternatives were not modeled because their potential effects on aquatic species were judged to be localized, small, and difficult to quantify given the methods available and basin-wide scope of the analyses of Flood Retention Alternatives that were conducted.

4.9 Small Flood Protection Projects

4.9.1 METHODS

The Anchor QEA consulting team developed three lists of flood protection projects as this component of the Project was implemented. The first list was developed through interviews with project stakeholders (HDR 2014d; Table 4.8). Projects on this list provided flood protection to specific areas or structures. The second list consisted of projects identified by Ecology and WDFW (n = 9; Table 4.8). Projects on this list were considered to potentially address flood protection requirements and have ecological benefits to aquatic species. The third list of 10 projects was developed during spring 2014 by the Anchor QEA consulting team after further discussions with stakeholders.

Each list of projects was assessed differently for the effects of the projects on aquatic species. The first list of eight projects identified through interviews with stakeholders were small in scale. All were judged to potentially affect non-salmonid fish and Non-fish Species, and none none were judged large enough to produce measurable effects on salmon species using the EDT or SHIRAZ models. Because the projects had not been sufficiently scoped as to their designs, the projects were assessed qualitatively for their potential effects on non-salmonid fish and Non-fish Species and the effects categorized as being positive, neutral, or no effect.

The second list of nine projects identified as being dual purpose (potentially having both flood protection and ecological benefits to aquatic specie) were evaluated previously and another assessment in this phase of the Project was not needed or conducted. In 2012, Anchor QEA reviewed Beechie et al. (2008) and selected four criteria to prioritize large-scale floodplain and riparian restoration actions: a tiered ranking of the limiting factors addressed; number of salmon species present; the size of the project; and certainty of response (Anchor QEA 2012b). The criteria were used to rate 53 floodplain and riparian projects, including the nine dual-purpose small projects listed in Table 4.8. The rankings of the nine projects developed in 2012 by Anchor QEA (2012b) were used to assess these projects in 2014, and no new analyses were conducted. In addition, two projects identified by Ecology and WDFW as potentially being dual-purpose projects were not reviewed in 2014 and are not listed in Table 4.8. The Gaddis Creek Fish Barrier Culvert Project in Grays Harbor County was a barrier removal with a narrow ecological scope compared to the other dual-purpose projects. The Allen Creek project would have only very localized effects on a small area, and the Allen Creek restoration project in Thurston County is being implemented.

The third list of small projects developed by the Anchor QEA consulting team is shown in Section 4.9.2.3. These projects were developed in spring 2014 and have not been sufficiently scoped at this stage of the Project to allow their potential effects on aquatic species to be analyzed.

Table 4.8
List of Small Flood Retention Projects Evaluated for Their Potential Effect on Aquatic Species

PROJECT LOCATION	PROJECT NAME
Projects Identified by Stakeholders	
City of Centralia	China Creek
City of Centralia/Lewis County	Salzer Creek
City of Chehalis	Airport Levee Phase 2
City of Chehalis	Dillenbaugh Creek Realignment
Confederated Tribes of the Chehalis Reservation	Roundtree Creek
City of Cosmopolis	Mill Creek
Grays Harbor County/City of Montesano	SR 107 Relic Channel Restoration
Lewis County	SR 6 Overflow
Dual-Purpose Projects Identified by Ecology and WDFW in 2012	
City of Centralia	RM 68 Oxbow Reconnection (109.4 RKm)
City of Chehalis	Stan Hedwall Park Floodplain Reconnection
Grays Harbor County	RM 36 Oxbow Reconnection (57.9 RKm)
Grays Harbor County	RM 43 Oxbow Reconnection (69.2 RKm)
Lewis County	WDFW Pheasant Farm
Lewis County	RM 78 Oxbow Reconnection (125.5 RKm)
Lewis County	Salzer Creek at Centralia Alpha Road Floodplain Storage and Riparian Restoration
Lewis County	Salzer Creek Lower Mile Oxbow Reconnection and Riparian Restoration
Lewis County	Oxbow Lake Reconnection

Note:
SR = State Route

4.9.2 RESULTS

4.9.2.1 PROJECTS IDENTIFIED THROUGH INITIAL INTERVIEWS WITH STAKEHOLDERS

The qualitative assessment of the small projects rated highest by the consulting team resulted in the following matrix (Table 4.9). Many of the scores could be positive or negative for various species depending on the design details. In general, no large trends in the matrix of effects stood out at this stage of analysis. For both Other Fish and Non-fish Species, the projects were judged to either be neutral or have a roughly equal balance of positive and negative effects across all species. Ambiguity in many responses reflects lack of information for many of these species related to project-specific conditions. Note that the State Route (SR) 107 Relic Channel Restoration Oxbow project was not clearly described and the ratings reflect a worst-case scenario.

Table 4.9
List of Small Flood Retention Projects Evaluated for Their Potential Effect on Aquatic Species

SPECIES	PROJECTS							
	CHINA CREEK	SALZER CREEK	AIRPORT LEVEE PHASE 2	DILLENBAUGH CREEK REALIGNMENT	ROUNDTREE CREEK	MILL CREEK	SR 107 RELIC CHANNEL RESTORATION	SR 6 OVERFLOW *
Non-fish Species								
Northern red-legged frog	0	-	±	0	0	+ or 0	-	0
Oregon spotted frog	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Western toad	0	-	±	0	0	0	-	+ or 0
Western pond turtle	0	-	±	0	0	n/a	n/a	+ or 0
North American beaver	0	-	±	+ or 0	+ or 0	0	0 or -	0
Other Fishes								
Pacific lamprey	+ or 0	-	±	+ or 0	+ or 0	±	-	+ or 0
White sturgeon	n/a	n/a	n/a	n/a	n/a	n/a	±	n/a
Chum salmon	n/a	n/a	n/a	n/a	+	±	0 or -	n/a
Eulachon	n/a	n/a	n/a	n/a	n/a	+ or 0	0 or -	n/a
Olympic mudminnow	+ or 0	-	±	0	0	+ or 0	-	+ or 0
Speckled dace	+ or 0	-	±	+ or 0	+ or 0	±	-	+ or 0
Largescale sucker	+ or 0	-	±	+ or 0	+ or 0	±	-	+ or 0
Riffle sculpin	+ or 0	-	±	+ or 0	+ or 0	±	-	+ or 0
Reticulate sculpin	+ or 0	-	±	+ or 0	+ or 0	±	-	+ or 0
Smallmouth bass	n/a	-	±	+ or 0	+ or 0	±	0	+ or 0
Largemouth bass	+	-	±	0	0	±	+	+ or 0

Notes:
*The SR 6 overflow project would require extensive floodplain work
+ denotes a positive effect
0 denotes a neutral effect
- denotes a negative effect
n/a = the species was not within the project range

4.9.2.2 DUAL-PURPOSE PROJECTS

Using the four criteria related to salmon discussed in Section 4.9.1, Anchor QEA (2012a) rated many of the dual-purpose as having high ecological value. Three of the dual-purpose projects were rated among the top 4 of the 53 projects rated (the first three projects listed below). The following four dual-purpose projects ranked within the first quartile of 53 projects that were rated:

- RM 43 Oxbow Reconnection (69.2 RKm)
- RM 36 Oxbow Reconnection (57.9 RKm)
- Oxbow Lake Reconnection
- RM 78 Oxbow Reconnection (125.5 RKm)

The following two dual-purpose projects ranked within the second quartile of 53 projects that were rated:

- RM 68 Oxbow Reconnection (109.4 RKm)
- WDFW Pheasant Farm

The following dual-purpose project ranked within the third quartile of 53 projects that were rated:

- Stan Hedwall Park Floodplain Reconnection

Finally, the two dual-purpose projects in Salzer Creek were ranked within the last quartile of 53 projects rated.

Oxbow lake reconnection projects should be evaluated on a case-by-case basis and will require monitoring in an experimental context for determining the effectiveness of restoration actions. Some oxbow lakes may support Olympic mudminnow and other native species that would be vulnerable to invasion by bass and other non-native predators, and it may be preferable to keep oxbow lakes that contain non-native fishes isolated to prevent their spreading to reconnected habitat. However, because responses here are uncertain (such restorations are unstudied in this context), it will be critical to evaluate their usefulness.

4.9.2.3 PROJECTS IDENTIFIED THROUGH ADDITIONAL INTERVIEWS WITH STAKEHOLDERS

Lastly, in addition to the preliminary assessments discussed previously, the consulting team developed the following list of 10 small projects based on additional discussions with stakeholders. Conceptual designs and preliminary cost estimates for these projects are being developed. The designs are very conceptual at this stage of development and have not been analyzed for their potential effects on aquatic species.

- Kirkland Road Flooding Study (City of Napavine)
- SR6 Bypass and Road Raise (Lewis County)*
- Dillingbaugh Creek Realignment (City of Chehalis)*
- Main Street Regrade (City of Chehalis)
- Salzer Creek (Lewis County)*
- Main Street Regrade (Town of Bucoda)
- Moon Road (Chehalis Tribe)
- Black River Bridge (Chehalis Tribe)
- Roundtree Creek (Chehalis Tribe)*
- Wynoochee Valley Road Regrade (Grays Harbor County)

*Projects also listed in Table 4.9.

4.10 Discussion of Results

4.10.1 EFFECTS ON SALMON SPECIES

Based on results of EDT model studies, changes in species abundance due to the FRO dam alternatives at the basin-wide scale were negative for all species. The percent change in abundance from the current condition ranged from a decrease of approximately 1% for fall-run Chinook salmon to a decrease of from 7 to 11% for spring-run Chinook salmon, depending on the FRO Alternative. At the basin scale, spring-run Chinook salmon and winter-run steelhead displayed the largest declines in abundance. This reflected the varying degrees of habitat change upstream from the proposed dam in the three FRO Alternatives as well as assumed geomorphic changes below the dam site. Both dam alternatives lessened flood peaks and thereby reduced off-channel habitat used by juvenile salmon in areas below the dams. However, while both dam alternatives lessened flood peaks, the FRO option did not provide a corresponding reduction in water temperature that did occur with the MPD Alternative.

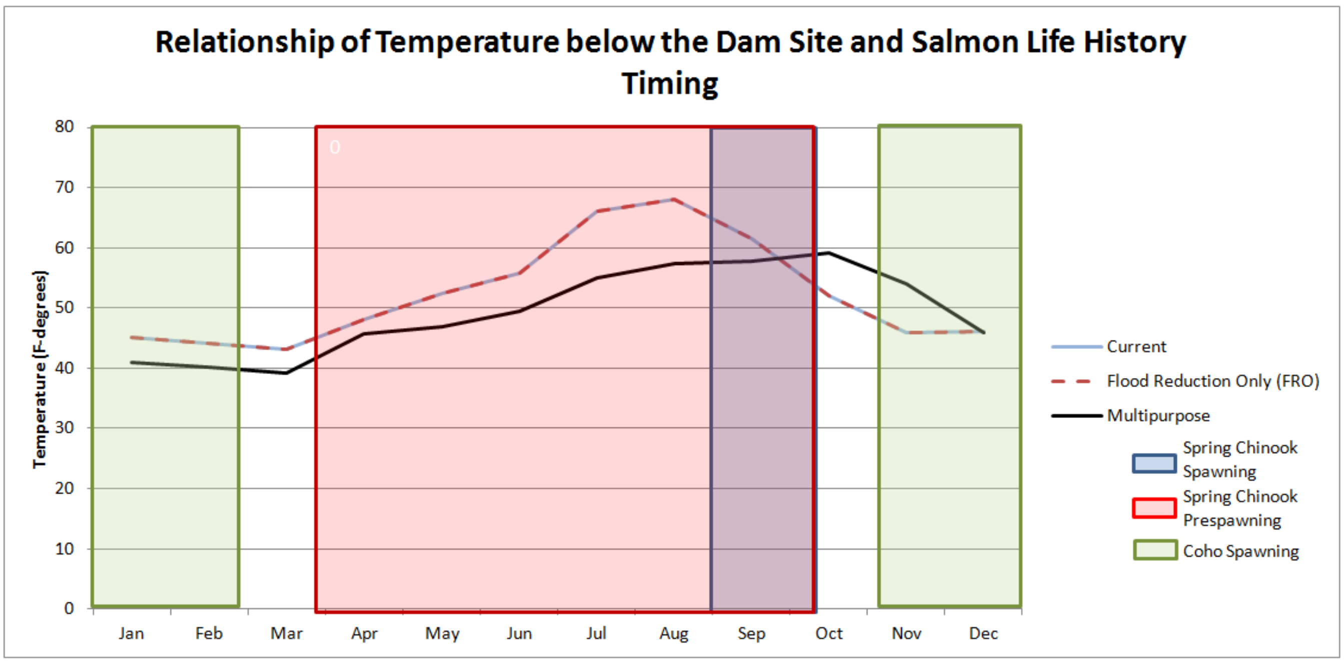
Also at the basin-wide scale, the MPD Alternative had negative effects on coho salmon and winter-run steelhead but positive effects on fall-run and spring-run Chinook salmon. Effects on coho salmon and steelhead resulted from the assumed passage mortality at the dam site and geomorphic changes below the dam site. The positive effect of the MPD Alternative on spring-run Chinook salmon, and to a much smaller degree, fall-run Chinook salmon resulted from assumptions related to a reduction in water temperature and scour, and from increased flow below the proposed dam.

At the sub-population scale, results of EDT model studies indicated that in general, the FRO Alternative resulted in poorer performance of the upper Chehalis sub-populations than did the MPD Alternative. The MPD Alternative resulted in positive changes in abundance of spring-run and fall-run Chinook salmon and winter-run steelhead, and a reduced abundance of coho salmon in the upper Chehalis River. The positive effects of the MPD Alternative were the result of a reduction in water temperature below the dam. These temperature reductions coincided with key life stages for the three species, especially spring-run Chinook salmon. Figure 4.23 compares the modeled temperatures below the dam for the current condition, and FRO and MPD Alternatives (Anchor QEA 2012c) juxtaposed on salmonid spawning periods. The reservoir behind the MPD Alternative was evacuated during summer and fall to provide environmental flows. The releases from the dam were assumed to be taken from below the thermocline resulting in reductions in temperature compared to the current condition and FRO Alternatives. These reductions in temperature coincided with spring-run Chinook salmon pre-spawning and spawning periods. Under the current condition and FRO Alternatives, water temperatures during the spring-run Chinook salmon pre-spawning holding period were quite high, which greatly limited the production of spring-run Chinook salmon from this reach of river in the model. Reductions in water temperature from the MPD Alternative relaxed this constraint and greatly benefited the production of spring-run Chinook salmon in the South Fork to Dam segment.

As discussed previously, where adult spring-run Chinook salmon hold in the Chehalis system prior to spawning is not known and represents a key uncertainty. The default modeling assumption used in this analysis was they hold near where they spawn. Ongoing research by USGS and WDFW may indicate that alternative assumptions are more likely that should be incorporated into the Chehalis EDT model. If spring-run Chinook salmon are able to find cooler water to hold during summer their modeled habitat potential would be higher relative to the modeled habitat potential under the MPD Alternative, in which case, the relative change in habitat potential resulting from the MPD would be less.

In contrast, coho salmon spawn considerably later during fall and winter when ambient water temperatures are low. Thus, the MPD Alternative provided no benefit from temperature reductions for upper Chehalis coho salmon sub-populations. Coho salmon abundance was reduced by the reduction in large wood and other geomorphic changes (Table 4.3). The smaller negative effect of the MPD Alternative on coho salmon compared to the FRO Alternative was because 1) rearing habitat was increased upstream from the dam site in the MPD Alternative even though spawning habitat was reduced, whereas in the FRO Alternatives the inundated reaches (which varied between FRO options) provided little habitat value; 2) bed scour was reduced below the dam site in the MPD Alternative to a greater degree than in the FRO Alternative; and 3) temperature was reduced in reaches below the dam site in the MPD Alternative but was unchanged in the FRO Alternative. The positive effects of the MPD Alternative on coho salmon were offset by the relatively high assumed passage mortality for this alternative.

Figure 4.23
Comparison of Water Temperature Below the Proposed Dam Site in the Flood Control Alternatives and Salmon Life History Stages



For middle and lower Chehalis River sub-populations, results were generally similar in their patterns among species as the upper Chehalis River sub-populations, but the proportional changes in estimated abundance were smaller.

Based on SHIRAZ, for the three species of salmon analyzed, the estimated size of these mainstem-only populations varied with the species and water retention alternative. For spring-run Chinook salmon, the estimated median number of spawners decreased by 59% under the FRO Alternative and increased by 5% under the MPD Alternative compared to existing conditions. The estimated median number of winter-run steelhead spawners decreased by 32% under the FRO Alternative and by 42% under the MPD Alternative compared to the existing conditions. The estimated number of coho salmon spawners decreased by 32% under the FRO Alternative and by 44% under the MPD Alternative. Changes in population size predicted by the model were immediate, after which the population numbers were relatively stable for the remainder of the analysis period. Because the range of estimated number of spawners was greatest under the existing conditions scenario and mostly decreased under both dam alternatives, and the changes in population sizes predicted were immediate, this suggests that salmon populations may be more vulnerable to years where returns are extremely low under dam alternatives compared to existing conditions. However, the reduced variability in population size that was observed under water retention alternatives was likely an outcome of decisions made when estimating future habitat conditions. Generally, habitat conditions in future years were based on the average conditions observed in last 20 years with a standard deviation around that average. Thus, estimates of future conditions were centered on average conditions applied across all variables, whereas the actual population sizes observed were the result of all conditions the population experienced. Differences in the estimated median number of salmon and steelhead spawners in the 2090 to 2099 period among treatment groups (existing conditions and water retention alternatives) were not tested using statistical methods. These are modeled data, not empirical observations, and use of statistical inference is this situation would be inappropriate. Thus, the results were plotted to aid visual comparisons among treatments.

Results of EDT and SHIRAZ model studies are not directly comparable. The two models were applied independently, used different data sources to populate habitat conditions for mainstem reaches, and spatial coverage of the population assemblages differed. However, in general the two models produced similar patterns in results among species and water retention alternatives. A qualitative comparison of results for mainstem salmon populations based on SHIRAZ to results at the basin scale based on EDT (see Figure 4.3) suggests that both models predicted effects to coho salmon and winter-run steelhead from both water retention alternatives, although the SHIRAZ results for mainstem-only populations were more similar between the water retention alternatives for these two species than were the EDT results. Both models also predicted effects to spring-run Chinook salmon from the FRO Alternative and benefits associated with the MPD Alternative.

4.10.2 EFFECTS ON OTHER FISH AND NON-FISH: IN-CHANNEL HABITAT

4.10.2.1 BASELINE

Overall, flows were more limiting in the Chehalis River basin upper reaches than the lower reaches as modeled by PHABSIM. Also, for monthly WUA comparisons, flows maximizing WUA for most species were limited during at least parts of the modeled year. In particular, low flow during the drier summer months appeared to be limiting for several species.

Modeled flows were found to reflect species' life histories and life stage requirements. Pacific lamprey spawn in late spring and early summer and summer low flows follow spawning, so the lamprey life history is synchronized with hydrology. This also highlights the dichotomous life history requirements of species at different life stages. Pacific lamprey spawning appears to be limited by flow during the spring and summer months. Increases in flow during this time frame under a MPD Alternative could increase WUA for spawning; however, other factors such as temperature should also be considered.

Of the bass species considered, largemouth bass WUA was not limited by flow and smallmouth bass WUA was only limited by flow from the Newaukum to Skookumchuck Rivers during the summer months and September. With the exception of the PHABSIM reach from the Newaukum River to the Skookumchuck River, speckled dace generally had maximum WUA at low flows and therefore were not limited by flow.

Largescale sucker WUA was not limited by flow upstream of the Newaukum River confluence; however, mountain whitefish spawning and rearing WUA was limited by flow upstream of the Newaukum River. As previously discussed, the differential response between largescale sucker and mountain whitefish likely reflects a combination of the basis of the modeled flow data for the sucker (at the location of the fish, which for suckers is bottom-dwelling) and the presumed location of flow modeled in PHABSIM (the water column over the fish). As discussed previously, given the tendency of largescale sucker to school with mountain whitefish and considering that HSIs of mountain whitefish were developed specifically for PHABSIM, the flows maximizing WUA for mountain whitefish are likely more representative of largescale sucker spawning.

Overall, seasonally weighted WUA showed decreases for speckled dace rearing, largescale sucker and western toad in the Pe Ell to Elk Creek reach and the Elk Creek to South Fork Chehalis River reach. This indicates that habitat available to these species would be decreased under the presence of the proposed MPD. Western toad is one of 113 species designated by Washington State as a Candidates Species for Endangered, Threatened, or Sensitive listing in Washington (WDFW 2013). Federally, it is a Species of Concern. Decreased habitat for western toad could translate into decreased species presence, which would further limit this Species of Concern. Seasonally weighted WUA also decreased for largemouth bass and smallmouth bass. A decrease in habitat for these non-native predators could translate into their decreased presence, which would positively affect the native fish in the associated areas.

4.10.2.2 CAVEATS FOR INTERPRETING PHABSIM RESULTS

The issues associated with PHABSIM modeling are discussed in the companion *Data Gaps Report*, and detailed studies should be conducted to validate HSIs and limiting factors for species and life stages modeled using PHABSIM are identified. The estimates of flow-habitat relationships based on existing PHABSIM modeling presented in this report should be viewed as being preliminary because of the following gaps and the following caveats regarding the PHABSIM analysis:

- *Habitat conditions in which a species is most frequently encountered are assumed to be the preferred range of habitat conditions*. For example, if a particular life stage of a species is most frequently encountered at a narrow range of water depths or velocities, then those depths and velocities are assumed to be the preferred range of habitat conditions for the species. This assumption ignores the idea that habitat utilized is not influenced by physical and/or biotic constraints, and the habitat parameters that describe habitat conditions, such depth, velocity, and substrate, are not entirely independent. For these reasons, determining habitat quality is challenging.
- *PHABSIM cannot assess certain aspects of how flow affects fish*. PHABSIM evaluates how modifying hydrology may affect fish habitat, but the WUA results enable only comparisons on selected aspects of species, life stages, and flows. Such aspects include migration stimulation (increase in flow), stranding (abrupt decrease in flow), scouring of redds (flooding), or contributions to intra-gravel incubation of salmon eggs. As a consequence, interpretation of WUA results requires thorough understanding of the life history of each species modeled as well as adequate understanding of typical hydrology of the stream.
- *Measurement location of current velocity preferences can influence PHABSIM results*. Current velocity preferences can be measured as the mean current velocity for the water column, a standard method of measuring current velocity, or at the specific locations at which a fish species or life stage was observed. Whether the current velocity experienced by a fish species (or life stage) or the mean column velocity at a vertical point above that fish (or life stage) represents the maximum current velocity it can negotiate is unknown. Because PHABSIM measures the overall velocity for the water column, this can create a problem evaluating PHABSIM modeling for benthic fish. Velocity next to the bottom, where benthic fish occur, is undoubtedly slower than the overall velocity for the channel (that typically used in PHABSIM). Hence, current velocity suitability for benthic fish may be mismatched if it is based on current velocities at the location of the fish rather than overall column velocities (for which mean column velocities are often used) and would cause velocity preferences to be underestimated.
- *PHABSIM results track changes in habitat, not changes in fish densities or abundance*. How much habitat (WUA) a fish needs also reflects its size. For example, speckled dace, which are only a few inches long as adults, need less space than adult largescale suckers, which can reach nearly two feet in length.

However, smaller fish are typically more numerous than larger fish, so the populations' needs for WUA may be comparable.

- *PHABSIM results were seasonally restricted*. PHABSIM modeling was limited by flow range, which typically does not capture peak flow levels during winter months. Hence, validation is required for species occupying in-stream habitat during winter months. Part of this limitation reflects difficulties associated with obtaining data and observing fish in turbid conditions, a typically pattern during peak flows.
- *Water temperature was not incorporated in PHABSIM*. Water temperature preferences by species were not included in PHABSIM modeling; however, when we compared overall, seasonally weighted WUA, we weighted monthly rearing WUA values based on approximate monthly water temperature as it is assumed WUA is more important during warmer months when cold-blooded vertebrates are more active. This is because temperature markedly influences ectothermic (cold-blooded) vertebrates such as fish and amphibians. At higher temperatures, ectotherms generally become more active and need more food and oxygen. They may also require more space (reflected as WUA) in which to live in order to meet their energetic (food) requirements. Selected temperatures (typically high temperatures for salmonid fishes) can be lethal, making some or all of available WUA irrelevant where these temperatures occur. Because much of the salmonid modeling indicates that temperature is focal and opportunities now exist to incorporate temperature into PHABSIM modeling, that should be a focus of any future efforts (as discussed in the companion *Data Gaps Report*).

4.10.2.3 SEASONALLY WEIGHTED, WEIGHTED USABLE AREA CHANGES FROM BASELINE TO PROPOSED MULTI-PURPOSE DAM FLOWS

Comparisons were made for changes in WUA for each species during months that were most applicable to that life stage, so the majority of comparisons occur during spring and summer months. Additionally, as mentioned previously, some winter flows are currently outside the calibrated range of PHABSIM. Therefore, resulting WUAs from proposed decreases in flows under water retention alternatives during winter months were not estimated.

Under the proposed MPD Alternative, changes in flow resulted in both increases and decreases of WUA, depending on species and life stage. Generally, rearing WUA decreased for all species except for mountain whitefish, which increased in May, July, and August. Decreased rearing WUAs are likely reflective of increased summer flows proposed by the MPD Alternative, which are undesirable for rearing of many species in the other fish group. Spawning WUA increased, during some months at least, for Pacific lamprey and mountain whitefish, and decreased during some months for smallmouth bass, largemouth bass, mountain whitefish, and largescale sucker. For those species that require higher flows for spawning (such as Pacific lamprey and mountain whitefish), spawning WUA increased for summer months when MPD operations would increase flows. Whereas, when species prefer lower flows for spawning during these months, their WUA decreased under the MPD's proposed increased flows. Western toad WUA decreased under the proposed MPD Alternative, for example. Pacific lamprey spawning appeared to be limited by flow during the spring and summer months, so increased flows proposed by the MPD Alternative increased WUA for spawning; however, Pacific lamprey rearing showed decreased WUA with increased flows during summer months.

WUA is a predictor of the amount of suitable space available to a species at a given life stage; however, other limiting factors outside of substrate, depth, and velocity can cause significant changes to a species success in spawning or rearing. It is likely that changes in WUA will have an effect on the species and life stage that follow the direction of WUA change; however, due to the lack of information regarding the factors that limit these populations, it cannot be concluded that these increases and decreases in WUA will consistently result in more or less individuals reaching maturity.

4.10.3 EFFECTS ON OTHER FISH AND NON-FISH: OFF-CHANNEL HABITAT

Inundation of the floodplain creates and maintains habitat and supplies water, sediment, and nutrients that are necessary to support off-channel species and habitats. Inundation likely affects ground water levels, hyporheic flow processes, nutrient cycles, soil properties, and water temperature. These processes are important to a greater or lesser degree to the entire suite of species (amphibians, beaver, and fishes) that occupy off-channel habitats. The Key Species identified from the Other Fish and Non-fish groups that occupy off-channel habitat in the Chehalis River at any life stage includes Olympic mudminnow, Pacific lamprey, speckled dace, largemouth bass, riffle sculpin, reticulate sculpin, largescale sucker, northern red-legged frog, Oregon spotted frog, western toad, western pond turtle, and North American beaver.

Translating water surface elevations at different flood levels into creation and maintenance of off-channel habitat for species dependent on those habitats is limited by not fully understanding the importance of inundation associated with peak flows (e.g., timing, magnitude, periodicity, etc.) to the creation and maintenance aquatic habitats. Therefore, for the purposes of this analysis, any species that could occupy off-channel habitat such as oxbows and wetlands at any life stage was considered to require such habitat. Moreover, we judged the effects of a dam based on an index of change in area affected.

Two Key Species, eulachon and adult white sturgeon, were not modeled by PHABSIM because no known habitat suitability criteria exist for these species. Because these species are not known to occupy off-channel habitats in the Chehalis River, they were not assessed using the two modeling techniques employed and their current use of the Chehalis River was not quantified. Based on their distribution and habitat requirements, predictions of how changes associated with proposed flood hazard reduction alternatives may affect their use of the river could not be made. Future studies of this would require analysis of their habitat requirements based on empirical information on occupancy patterns within the Chehalis system and subsequent modeling under current and proposed conditions.

It is important to note several caveats associated with this simple approach for modeling changes in off-channel habitat. The approach does not:

- Consider connections of these off-channel habitats to the main channel or possible inputs from tributaries, which could alter the acreage of inundation.
- Consider the possibility that off-channel aquatic habitat is maintained by upland drainage or groundwater relatively unassociated with the river flooding.
- Include an analysis of hydroperiod (length of time of inundation) based on the duration of flood events and the water outflow/infiltration following the flood events, or changes to channel and off-channel morphology due to major flood events.
- Account for effects of changes to sediment delivery under different dam operation conditions.
- Consider how the creation and maintenance of off channel habitat relates to inundation acreage, that is, whether a 10 % reduction of inundation also reduces the maintenance of existing and creation of new habitat by 10%.

The western toad may also be a Washington State Species of Special Concern in the Chehalis basin because of its breeding habitat distribution with respect to the proposed dam. Western toad is a stillwater-breeding species. However, all evidence of western toad breeding during surveys conducted in 2013 and 2014 during the declining hydrograph in early summer was restricted to localized off-channel habitat pockets along the mainstem Chehalis River. Most of the observed breeding sites were located within the footprint of the water retention dam reservoir adjacent to managed forest uplands. No evidence of western toad breeding was observed in stillwater, off-channel habitat in the extensive floodplains of the Chehalis River where adjacent plans have been developed for agriculture. Moreover, these habitats are non-native-predator-rich and lack the open, shallow margins western toads use for breeding due vegetation. Hence, the installation of a MPD in the upper Chehalis basin could eliminate most of the observed breeding habitat of western toad, while reducing breeding and rearing habitat downstream due to increased flows of colder water being released. However, there is uncertainty associated with these assumed effects to western toad associated with an MPD. This is because surveys for western toad in the basin have not been comprehensive, and because the suitability of reservoir margins for toad breeding has not been assessed but may be effected by water level fluctuations during project operations.

4.10.3.1 CHANGE IN AREA OF FLOODPLAIN INUNDATION BETWEEN DAM AND NO-DAM CONDITIONS UNDER VARIOUS FLOOD EVENTS

An inundation area decreased under the water retention alternative modeled for the 500-year, 100-year, 20-year, and 10-year flood events. The patterns shown by the changes in inundation for the dam and no-dam scenarios reflect both the different floodplain morphologies within each river segment and flow contributions from other tributaries under flood conditions that dilute the effects of a dam located in the upper basin on flows. A second general pattern of results was that the index increased with increasing flood size, indicating that larger floods have generally larger indices across all river reaches. This pattern reiterates the point that a dam can only reduce flows so much, and the effect of a water retention structure on flow decreases with increasing peak flows.

For the change in area beyond the bankfull width inundation for the 20-year flood (Figure 4.20), the amount of acres inundated is dramatically reduced for both the dam and no-dam alternatives but the inundation indices are much higher. This result may reflect the different morphology of the main river channel, which may hold a relatively large volume of water per unit area compared to the floodplain, which is generally flatter and wider outside of the main channel.

Species that occupy off-channel areas in the floodplain depend on the creation and maintenance of off-channel habitat, which evolves in part from inundation due to major flood events (Junk et al. 1989; Trush et al. 2000). Based on this relationship and for the purposes of this first phase of analysis, ASEP authors assumed that a decrease in inundation would have a negative effect on the off-channel suite of species whereas an increase in inundation would have positive effect on these species. For Other Fish Species, this includes Pacific lamprey juveniles, Olympic mudminnow (all life stages), speckled dace, largescale sucker juveniles, riffle and reticulate sculpin, and largemouth bass. For the Non-fish Species, this includes three key amphibian species (northern red-legged frog, Oregon spotted frog, and western toad), the western pond turtle, and North American beaver.

Pacific lamprey, Olympic mudminnow, western toad, Oregon spotted frog, Dunn’s salamander, Van Dyke’s salamander, and western pond turtle are all listed as species of concern, priority species, and species of greatest conservation need. Additionally, riffle and reticulate sculpin are species of concern. These different lists highlight species that require conservation and/or use habitat that is threatened or State Endangered, State Threatened, State Sensitive, or State Candidate Species.

An important example of a species requiring conservation is the Olympic mudminnow. It is one of eight State Sensitive Species. State Sensitive Species are defined as being a species native to the State of Washington that is vulnerable or declining and is likely to become endangered or threatened in a significant portion of its range within the state without cooperative management or removal of threats (WDFW 2013). They are known to inhabit the Chehalis basin and were identified in only one of the seven oxbows sampled during the WDFW off-channel sampling in 2013 and was not found in the two oxbows WDFW sampled in 2014.

Applying this status to the Project, a loss of habitat for Olympic mudminnow in a region where it is known to occur could further reduce their already limited distribution and result in a negative outcome for an action. However, the caveats associated with this modeling technique and a lack of knowledge of specific habitat use by these species in the Chehalis basin increase the uncertainty of this assumption. It is important to also note that if flood events are responsible for maintaining off-channel habitat that supports these species, reducing the flood events by installing a dam in the upper Chehalis River would result in the off-channel habitat not being maintained, and over time, this habitat would not available to the species that depend on it.

Along with native species, non-native species occupying off-channel habitats, such as largemouth bass, could be negatively affected by loss of habitat as well. Because non-native species compete for food and spawning habitat with native fishes, and prey on native fishes, this negative effect of habitat reduction could positively benefit native fishes. On the other hand, a decrease in off-channel habitat for all these species would concentrate their presence in remaining off-channel acreage, which would increase pressure of predation on native species. As a consequence, interpretation of the outcome of inundation changes will be ambiguous at this level of analysis where non-native aquatic predators, especially fishes, are present. It is important to note the caveats associated with this simple assumption are similar to those noted in Section 4.10.3, and also include the following:

- The method used to assess changes in area of floodplain inundation associated with a dam does not separate out changes anticipated under both of the dam alternatives that are being proposed. Therefore, this analysis does not account for potential changes in the hydrographs created from truncating flows from the upper Chehalis region and it does not include increased inputs from augmented summer flows included with the MPD Alternative.
- The method used to assess changes in area of floodplain inundation associated with a dam does not address inundation effects resulting from dam reservoirs.

5 Analysis of Climate Change

5.1 Introduction

Changes to a basin associated with climate variability are important considerations for any long-term planning effort, including studies of flood hazard reductions and the enhancement of habitat for aquatic species in the Chehalis River basin. This is because the changes can have major implications for species and habitat conditions (Mantua et al. 2009; Crozier and Zabel 2006). Changes in the ecosystem from climate could alter—positively or negatively—the availability and quality of suitable habitats for aquatic and semi-aquatic species. These changes could also affect population responses to flood hazard reduction or habitat enhancement activities. The purpose of this climate change analysis was to provide decision makers with information on how a range of projected changes associated with climate may affect species in the future.

5.2 Estimating Climate Change

Climate change projections for the region are available from the Climate Impacts Group (CIG) at the University of Washington. The CIG uses multiple models to downscale global projections from the Intergovernmental Panel on Climate Change (IPCC) to smaller geographic areas such as the Pacific Northwest, Washington State, and specific watersheds.

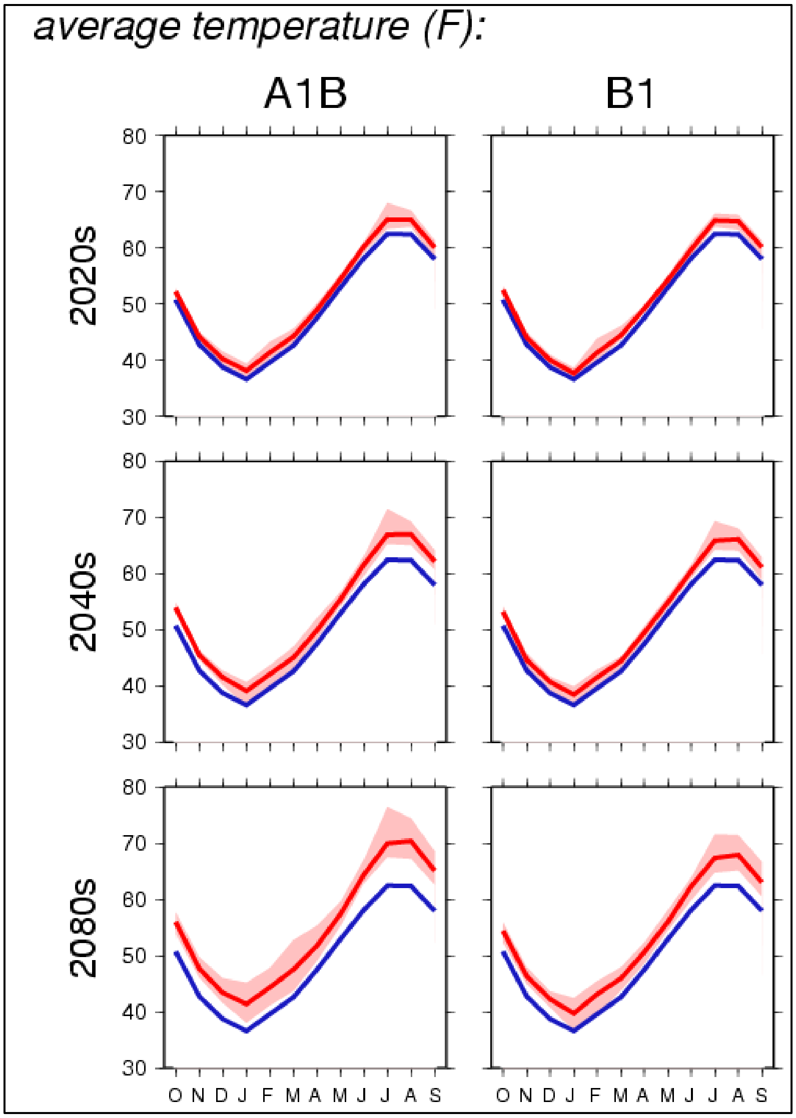
The sensitivity analysis conducted in this analysis based on CIG data considered changes to three parameters: water temperature, stream flow, and sea level. The effects of changes in temperature and flow were modeled, whereas changes in sea level were discussed qualitatively during meetings but no analyses of sea level rise were conducted in the ASEP. However, the Wild Fish Conservancy's description of selected modeling of sea level changes anticipated for the Chehalis estuary are briefly discussed in section 5.2.3. The available information on each parameter and a recommended scenario to incorporate it are described in the following paragraphs.

While the potential parameter changes are consistent with available projections, considerable uncertainty exists about the magnitude and timing of changes and precisely what changes will occur. Projected changes associated with climate change depend on future projections of greenhouse gas emissions. The climate change projections used in this analysis were based on projections from the A1B greenhouse gas emissions scenario where emissions increase gradually during the 21st century and stabilized in the final decades. Note that this was a moderate—not an extreme—emissions scenario.

5.2.1 PROJECTED CHANGES IN WATER TEMPERATURE BASED ON AIR TEMPERATURE CHANGE PROJECTIONS

Widespread consistency exists among models and across all emission scenarios that warming is expected to continue throughout the century, including the Chehalis basin (Figure 5.1). For the Chehalis basin analysis, the necessary model inputs are water temperature, not air temperature. Air temperatures influence water temperatures, but the relationship between the two parameters varies depending on season and site-specific conditions such as stream flows and shading. For this analysis, changes in air temperature were assumed to reflect expected changes in water temperature. That is, projected absolute changes in water temperatures were assumed to be identical to the projected absolute changes in air temperature. This simplified approach to approximating water temperature changes was deemed appropriate given the uncertainty of any projections over the 80-year time period modeled, and because it has been applied in other studies of potential climate change effects and was supported by empirical data (Ducharme 2008).

Figure 5.1
Average Air Temperature in Degrees Fahrenheit: Chehalis River at Grand Mound



Notes:
Blue lines indicate existing conditions, red lines indicate average of simulated climate change ensemble, and pink bands indicate range of conditions within simulation ensemble.
Source: CIG 2010.

Table 5.1 presents the projected changes in water temperature used in the analysis.

Table 5.1
Water Temperature Changes to Be Included in the Climate Change Sensitivity Analysis Based on A1B Emissions Scenario

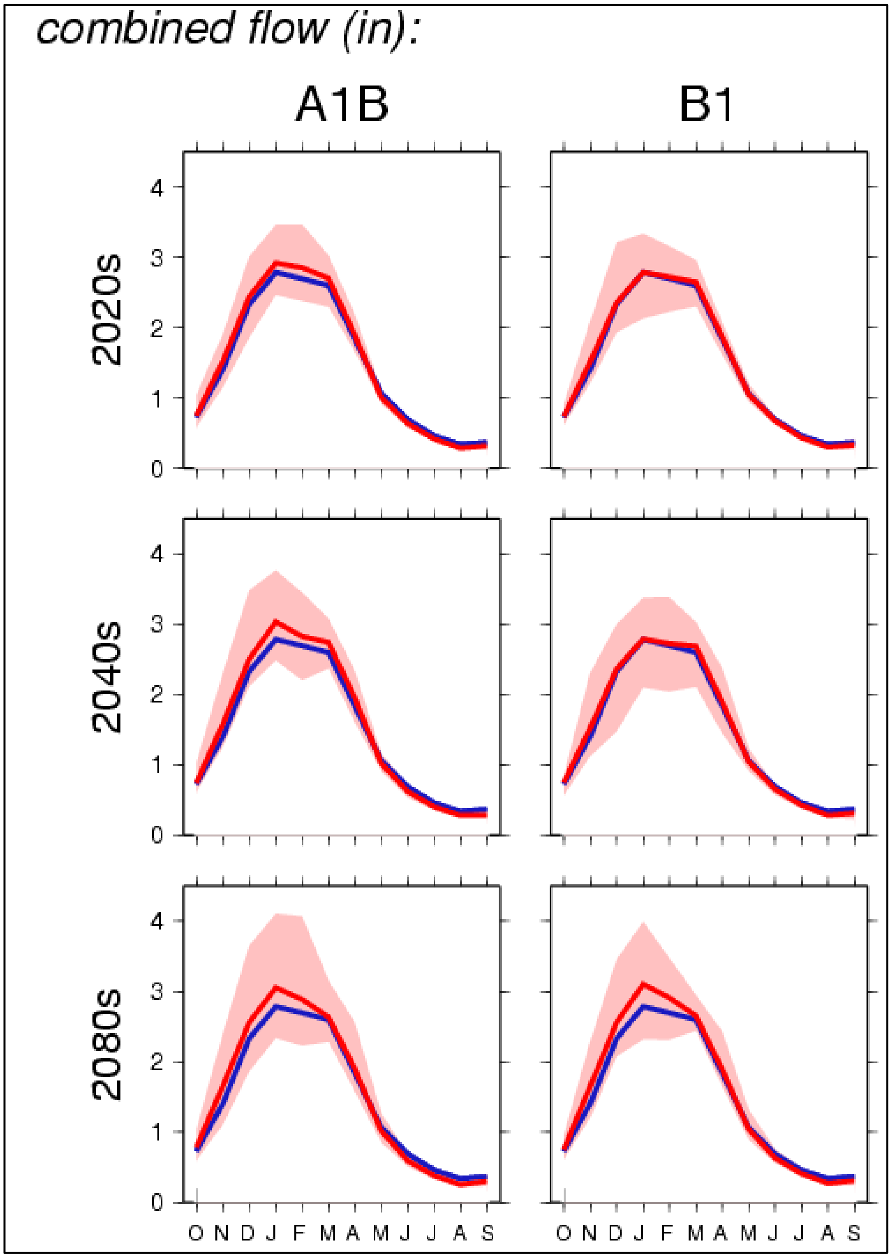
MONTH	CHANGE IN AVERAGE TEMPERATURE (ºC)		
	2020s	2040s	2080s
January	+0.8	+1.4	+2.6
February	+1.0	+1.4	+2.6
March	+0.9	+1.4	+2.7
April	+0.8	+1.3	+2.4
May	+0.8	+1.4	+2.5
June	+1.1	+1.9	+3.5
July	+1.4	+2.5	+4.2
August	+1.5	+2.6	+4.4
September	+1.1	+2.3	+3.9
October	+0.8	+1.8	+2.9
November	+0.8	+1.5	+2.7
December	+0.8	+1.6	+2.6

5.2.2 STREAM FLOWS

In contrast to the high degree of concurrence among climate models showing that temperatures will continue to warm throughout the century, considerably less consistency exists in the types of changes projected for precipitation and stream flow. The patterns of change for these parameters are less clear and are generally projected to be smaller than natural year-to-year variability (Snover et al. 2013). In rain-dominated systems such as the Chehalis River basin, the stream flow changes are expected to be less significant than in snow-dominated or mixed rain and snow watersheds. This is because for watersheds currently receiving significant portions of the annual precipitation in the form of snow, the warmer temperatures will result in more precipitation falling as rain and less moisture being stored in the snowpack (or for a shorter period of time). In rain-dominant systems, precipitation will continue to fall primarily as rain and runoff patterns would reflect precipitation patterns and events.

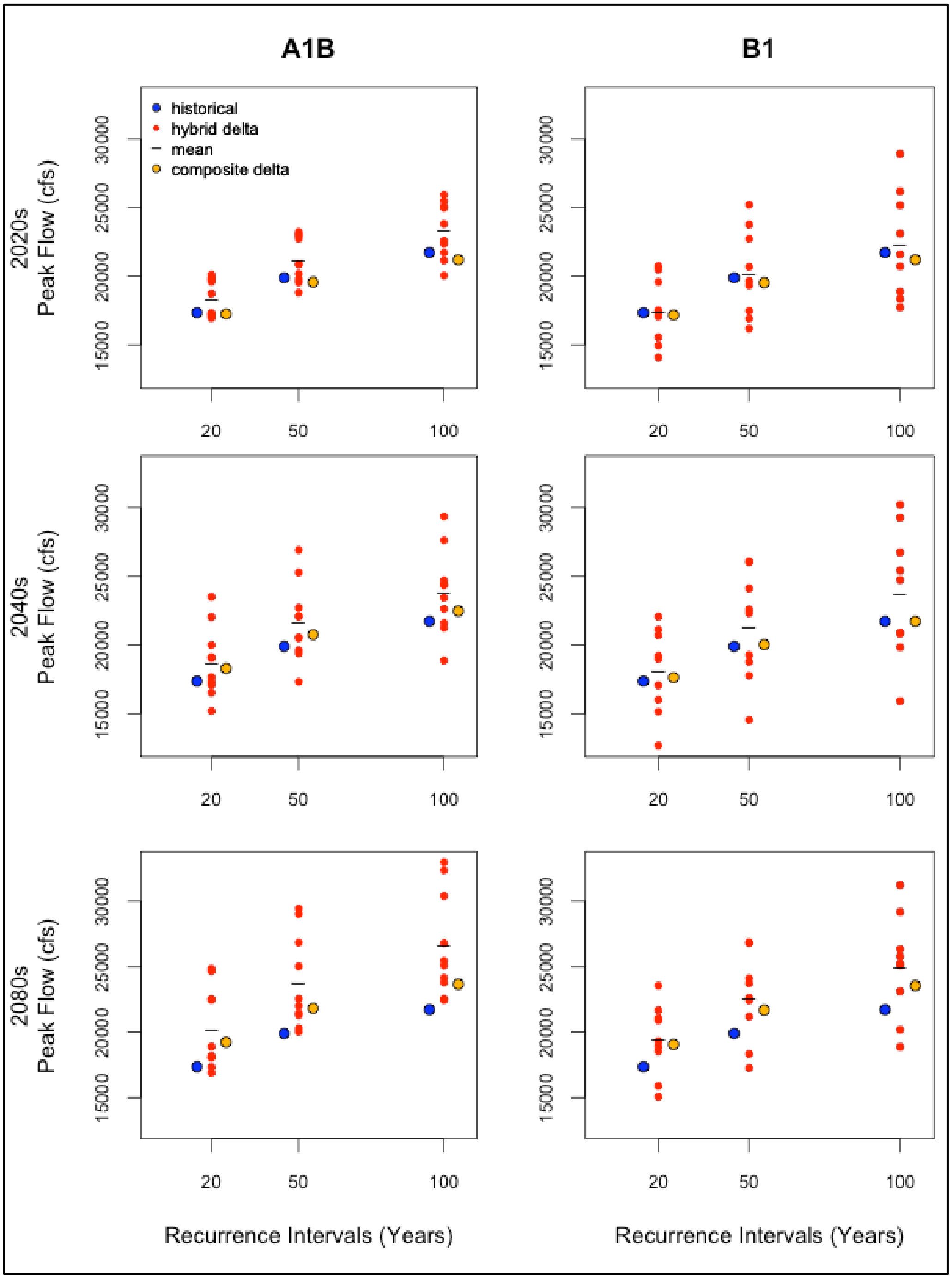
While stream flow projections are available for the Chehalis basin, the models are poorly calibrated to historical conditions. For example, the modeled historical data shows maximum daily discharges at Grand Mound ranging from 17,000 cfs to 22,000 cfs (481.4 to 623 m^3/sec) for the 20- to 100-year events (CIG 2010). In contrast, the historical gage data show the actual daily flow quantities ranged from 47,000 cfs to 64,000 cfs (1,330.9 to 1,812.3 m^3/sec) at these same recurrence intervals (USACE 2013). Hydrologic experts on the consultant team advised caution when using the CIG projections until the calibration is improved. Based on this recommendation, CIG projections of daily average flows through 2099 were not used. Instead, the analysis used the relative changes from historic to future conditions as a scaling factor to adjust empirical data obtained from USGS gages. Figure 5.2 presents the monthly total runoff projections. Figure 5.3 presents the annual maximum daily flow projections at Grand Mound. Figure 5.4 presents the annual minimum daily flow projections.

Figure 5.2
Monthly Total Runoff in Inches: Chehalis River at Grand Mound



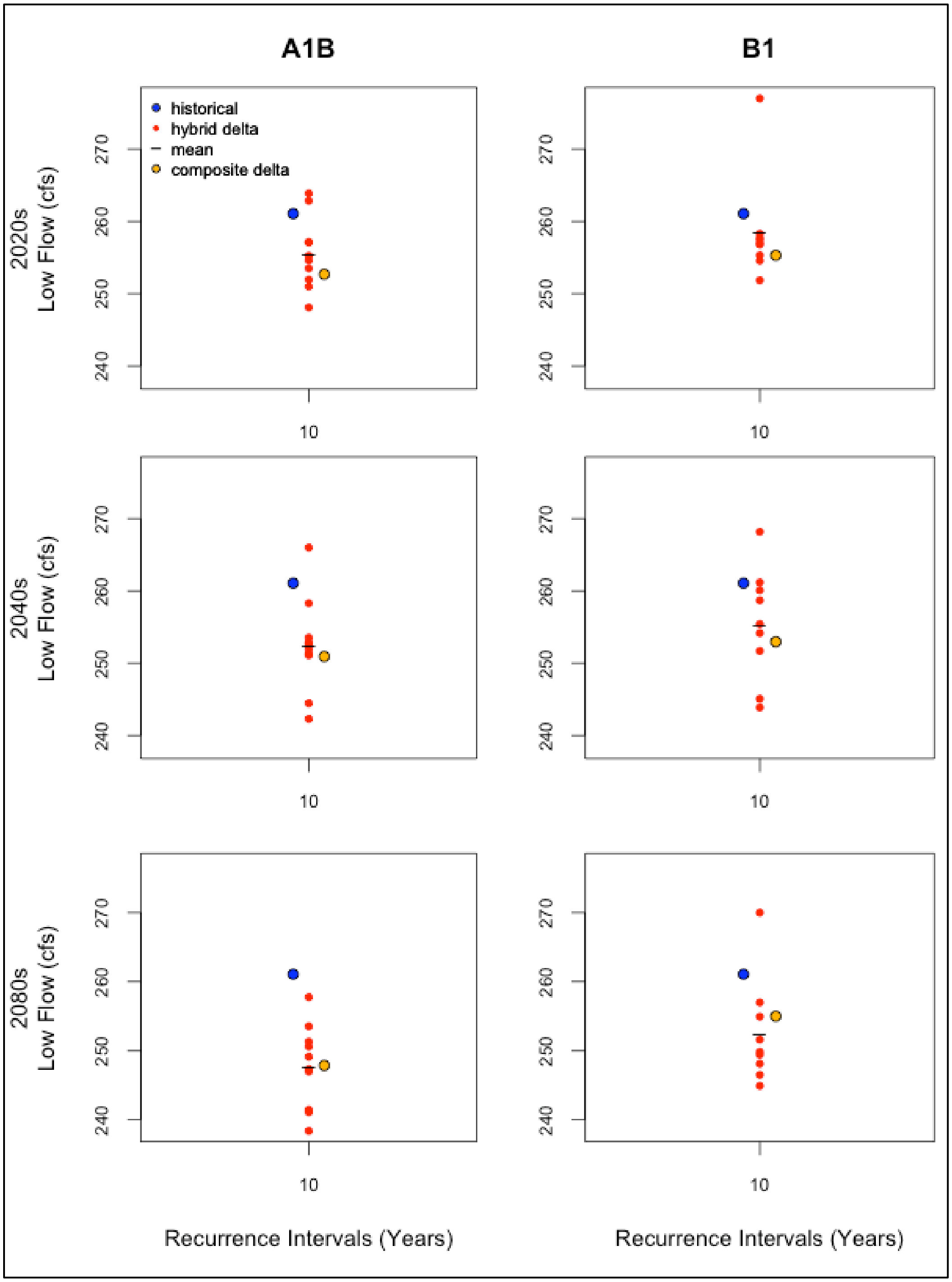
Notes:
Blue lines indicate existing conditions, red lines indicate average of the simulated climate change ensemble, and pink bands indicate range of conditions within simulation ensemble.
Source: CIG 2010.

Figure 5.3
Annual Maximum Daily Flow Projections: Chehalis River at Grand Mound



Notes:
Blue dots represent the simulated historical value; the red dots show the range of values from the hybrid delta downscaling scenarios; the black dashes show the average of the hybrid delta downscaling scenarios, and the orange dots show the value calculated for the composite delta scenarios. The composite delta downscaling method applies a constant change in temperature and precipitation over the entire spatial domain, whereas the hybrid delta method provides more detailed spatial distribution of climatic shifts.
Source: CIG 2010.

Figure 5.4
Annual Minimum Daily Flow Projections: Chehalis River at Grand Mound



Notes:
Blue dots represent the simulated historical value; the red dots show the range of values from the hybrid delta downscaling scenarios; the black dashes show the average of the hybrid delta downscaling scenarios, and the orange dots show the value calculated for the composite delta scenarios.
Source: CIG 2010.

The percent change in monthly total runoff presented in Figure 5.2 based on CIG estimates are reported in Table 5.2. These changes were used as estimates of the percent change in daily average runoff. The potential changes associated with the A1B emissions scenario in the recurrence interval of maximum and minimum annual daily discharges are presented in Table 5.3. These were estimated based on interpretation of the historical and mean values in Figures 5.3 and 5.4. The flow changes presented in Table 5.3 were the recommended peak flow and low flow changes considered in SHIRAZ sensitivity analysis where modeling was based on year-round flows. Modeling of climate change for Other Fish and Non-fish species used PHABSIM, for which modeling was restricted to the summer months (July through September), which used the percent change in daily average stream flow for those months as shown in Table 5.2.

Table 5.2
Percent Change in Stream Flow to Be Included in the Climate Change Sensitivity Analysis Based on A1B Emissions Scenario

MONTH	PERCENT CHANGE IN DAILY AVERAGE STREAM FLOW		
	2020s	2040s	2080s
January	+4.7%	+9.2%	+9.8%
February	+5.8%	+4.9%	+7.2%
March	+3.8%	+5.5%	+1.4%
April	+2.8%	+6.1%	+3.3%
May	-4.7%	-3.7%	-4.4%
June	-7.3%	-9.2%	-13.3%
July	-9.6%	-11.6%	-16.8%
August	-14.1%	-17.2%	-26.0%
September	-13.0%	-20.6%	-18.4%
October	+2.6%	+2.6%	+7.3%
November	+8.3%	+12.6%	+17.7%
December	+4.8%	+7.5%	+10.0%

Table 5.3
Recommended Peak Flow and Low Flow Changes Included in Sensitivity Analysis Based on A1B Emissions Scenario

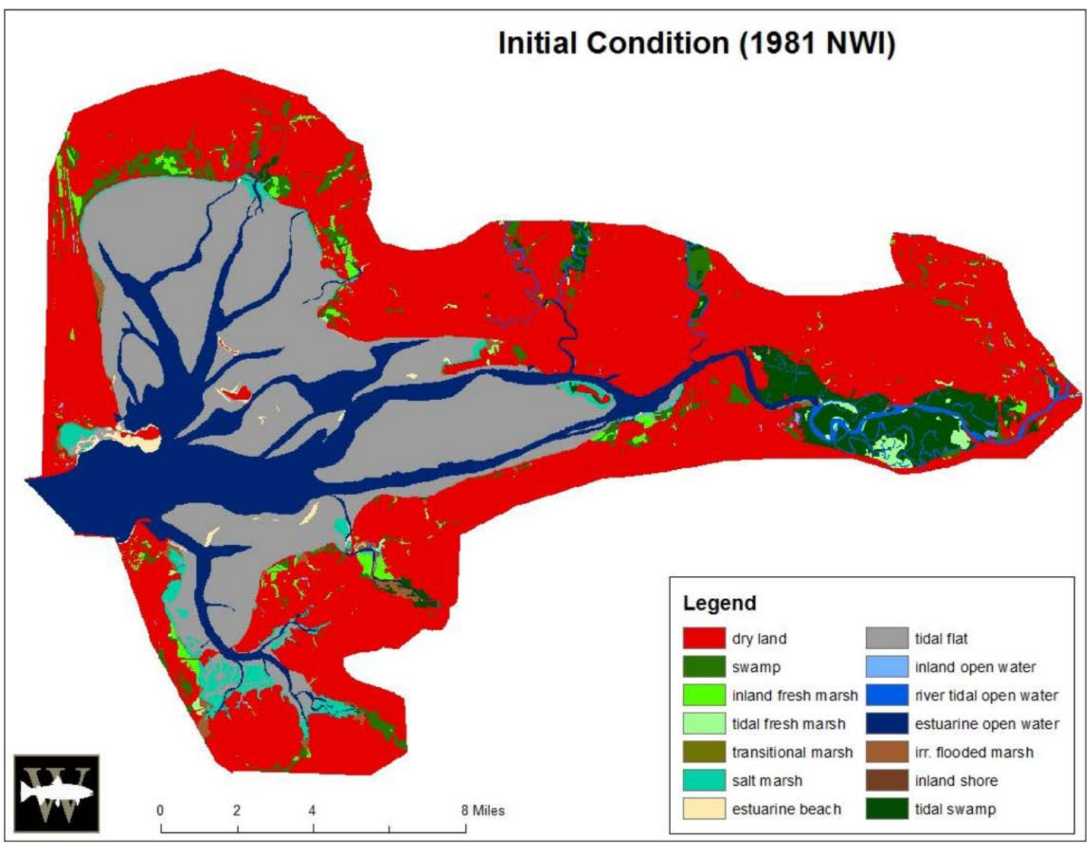
		CHANGE IN PEAK FLOW		
	RECURRENCE INTERVAL	2020s	2040s	2080s
Peak Flows	20-year maximum daily	+6.0%	+8.0%	+16.3%
	50-year maximum daily	+6.6%	+8.8%	+19.6%
	100-year maximum daily	+7.4%	+9.6%	+22.4%
Low Flows	10-year minimum daily	-2.1%	-3.3%	-5.1%

5.2.3 SEA LEVEL RISE

Although the climate analyses described in this report focused on river areas above the influence of tides, sea level rise may affect the location and availability of various habitat types as inundation patterns and salinity patterns shift in the lower river and estuary. An analysis by Wild Fish Conservancy (WFC) applied current projections in sea level change to estimate changes in habitat distribution in the Grays Harbor estuary, including the lower extent of the Chehalis River (WFC 2011). Analysis was based on the Sea Level Affecting Marshes Model (SLAMM), which "simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise." The WFC modeled changes using three sea level rise scenarios. The A1B greenhouse gas emissions scenario projects 23 inches (59 centimeters) of sea level rise by 2100. Figures 5.5 and 5.6 show the projected habitat distributions in the Grays Harbor estuary based on National Wetland Inventory 1981 maps and SLAMM projections for years 2025, 2050, and 2100.

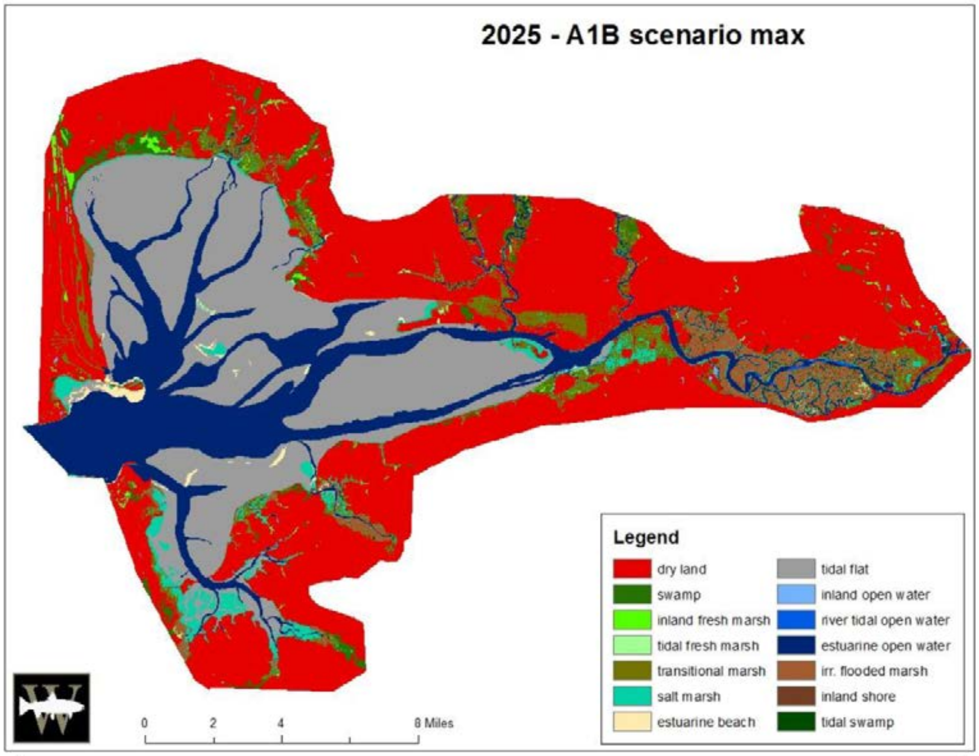
As shown in Figures 5.5 and 5.6, sea level rise is predicted to result in a rapid transition of wetland habitats in the lower river surge plain area from a forested tidal swamp to irregularly flooded marsh by 2025. Many of the trees in this area are expected to die due to rising water levels and increased salt-water intrusion into the lower river. In the inner estuary and greater Grays Harbor, there will be extensive loss of low elevation tidal mud and sand flats.

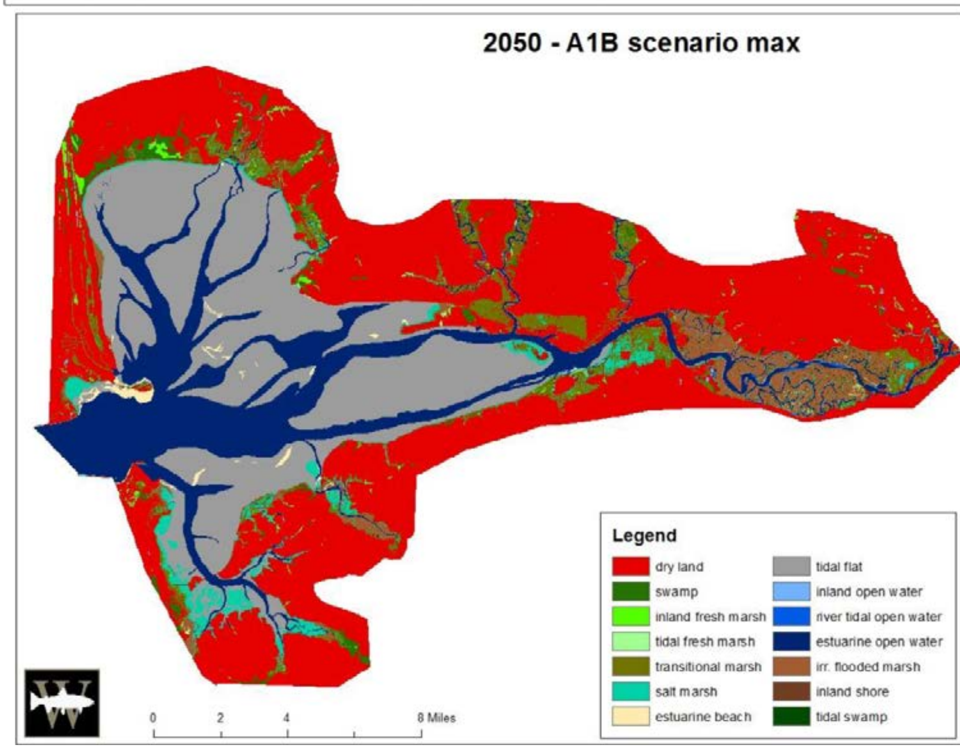
Figure 5.5
Estimated Habitat Distributions in Grays Harbor under Existing (1981) Conditions



Note:
Source: WFC 2011.

Figure 5.6
Estimated Habitat Distributions in Grays Harbor in 2025 (top) and 2050 (bottom) Assuming A1B Maximum Emissions Scenario Projections for Sea Level Rise





Note:
Source: WFC 2011.

5.2.4 SUMMARY OF PROJECTED CHANGES TO THE CHEHALIS BASIN

Climate change predictions suggest changes in quantity, timing, and intensity of precipitation that will translate into changes in flow magnitude and perhaps changes in the frequency of flood events. Projections for the Chehalis basin are anticipated to have less change in stream flow than snow-dominated systems. However, by mid-century, rainfall events are projected to become more severe, summer stream flows are projected to decrease, and annual variability will continue to cause some periods that are abnormally wet, and others that are abnormally dry.

5.3 Methods

As with other aspects of the study, the climate change analysis addressed a diverse set of aquatic species. The analysis for each was more or less quantitative depending on the amount of available information on the species' ecological requirements and habitat conditions in the basin.

5.3.1.1 SALMON HABITAT MODELS

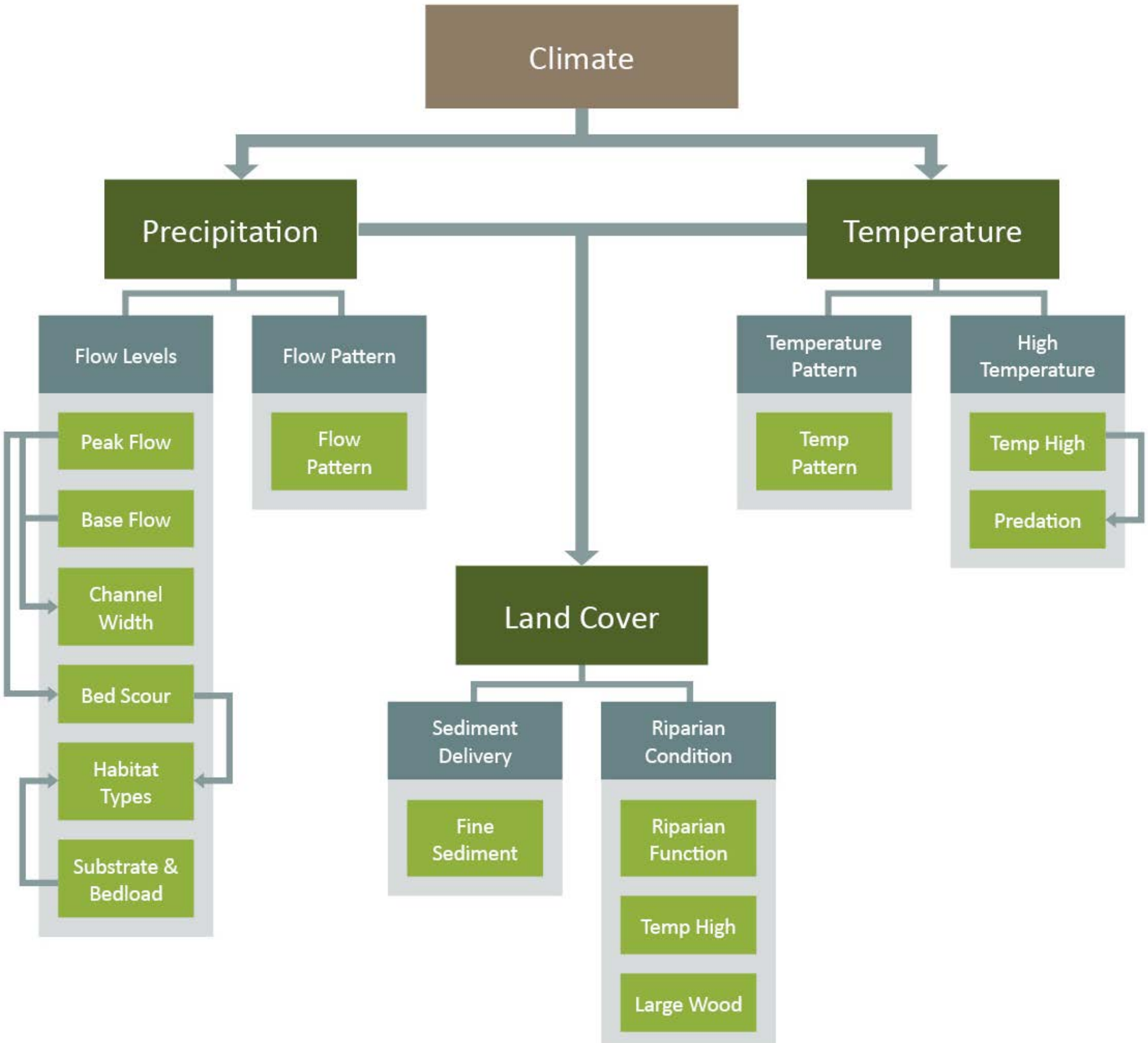
The projected changes to water temperatures and stream flows associated with climate change were input into the SHIRAZ model as described above. SHIRAZ modeled one scenario that reflected the changes identified in the preceding tables and associated with the A1B greenhouse gas emissions scenario, and applied these changes to mainstem-only populations of three salmon species. However, the assumptions, spatial coverage, and species addressed with each salmon habitat model differed. To incorporate a broader suite of salmon species, variables, and spatial scale into the analysis of potential effects of climate change on salmon, two future climate scenarios were modeled using EDT: a high and low estimate of climate change based on assumption of higher winter flows, lower summer flows and warmer water temperatures. These scenarios were applied to four salmon species across the basin and are described in greater detail in Section 5.3.1.1.2.

5.3.1.1.1 Ecosystem Diagnosis & Treatment

Assumptions regarding alternative future environmental conditions were incorporated to the entire stream network in the Chehalis basin. EDT evaluates potential salmonid production for a given environmental condition that can be compared to potential production in another condition, including alternative future climates. Salmonid production under current environmental conditions was compared to the estimated production under alternative conditions that are consistent with the available scientific information on regional climate change impacts. The alternative climate scenarios were not intended to represent conditions in any particular year, nor the downscaling of a specific regional climate model. The intent of the analysis was to conduct a sensitivity analysis and estimate fish production under alternative future conditions given the available scientific information on climate change.

A simple conceptual model of how climate change could affect aquatic conditions in the basin is shown in Figure 5.7. Climate controls conditions in aquatic systems such as the Chehalis system through two primary processes, precipitation and temperature (Edmonds et al. 2003). Climate determines the amount, pattern, and form (snow or rain) of precipitation in a basin. Air temperature, resulting from solar radiation, wind, and weather, is a large determinant of water temperature and the annual pattern of water temperature. Precipitation and temperature also affect land cover as a result of their effect on fire frequency and vegetation patterns, which may lead to higher erosion and sediment delivery and loss of riparian cover (Dale et al. 2001).

Figure 5.7
Conceptual Model of Climate Controls on Aquatic Environments



Note: Green boxes indicate attributes in EDT that can be adjusted to estimate alternative future environmental conditions.

Climate change in the future can be expected to alter environmental conditions in the Chehalis River and produce significant changes in species distribution and abundance, through changes in ecological functions and services. Figure 5.7 shows attributes in the Chehalis EDT model that are expected to change and the direction of change as a result of the climate scenarios modeled. These attributes and changes were used to estimate the effects of climate change scenarios on populations of coho salmon, fall-run and spring-run Chinook salmon, and winter-run steelhead.

5.3.1.1.2 Climate Change Alternatives Modeled Using EDT

Although the broad outlines of climate change are relatively well defined at global and regional scales (Independent Scientific Advisory Board 2007), they are less defined at watershed scales. At finer scales of resolution, variability and uncertainty in downscaled model predictions increases. Even the direction of change in precipitation, stream flow, and other attributes can differ between downscaled model data at finer scales.

The University of Washington Climate Impacts Group (Snover et al. 2013) summarized climate modeling results for Washington State and found that model results are, "mixed, but most models predict an increase in annual stream flow" but that "models disagree on the direction of change." Regarding winter flow, most models project an increase in winter stream flow on average for Washington State ranging from 25% to 34% by year 2080. The models predict a decrease in summer stream flow from 44% to 34% by year 2080. Stream temperatures are expected to increase in most future climate projections with changes to summer water temperature likely to be significant in terms of salmonid production (Mantua et al. 2010). Snover et al. (2013) summarize modeling results for stream temperature and concluded that locations in western Washington that will experience temperatures that are stressful to salmonids (more than 67^{o}F [19.4^{o}C]) will increase by 16%, and many locations will exceed 70^{o}F (21.1^{o}C) for the entire summer by year 2080, a situation that would be lethal for most salmonids.

Based on these analyses, it was hypothesized that under future climate conditions, winter flow in the Chehalis River is likely to increase, summer flows would likely decrease, and summer water temperatures are likely to increase. However, the specific changes in these attributes in the Chehalis basin are uncertain and cannot be predicted with the available analytical tools.

Therefore, to capture a range in these predicted trends and how evaluate how this range might affect salmon two alternative future conditions were developed and assessed using EDT. These were based on changing the attributes as identified in the conceptual model (Figure 5.7). These two alternative futures are characterized as "Low Climate Change" and "High Climate Change" alternatives (Table 5.4). These alternatives are based on the flow record from 1989 to 2012, where each WY was analyzed and placed into one of five categories: Wet, Normal Wet, Normal, Normal Dry, and Dry. HEC-RAS model outputs of WYs selected to represent each category provided quantitative estimates of the flow and changes in wetted width of the channel expected in each WY. All EDT analysis other than the climate change analysis described in this report are based on a HEC-RAS depiction of flow and channel width in the mainstem Chehalis River for the Normal WY condition. The Low Climate Change scenario was constructed by combining the HEC-RAS analyses of Normal Wet and Normal Dry WY conditions, consistent with the assumption of wetter winter and drier summers. The High Climate Change scenario was constructed by combining the HEC-RAS analyses of Wet and Dry WY conditions, consistent with the assumption of much wetter winters and much drier summers. Under both scenarios, no changes to the water retention alternatives were assumed in regard to operations or conditions within the reservoir footprint.

In addition to the change in channel width, a second key effect of increased winter flow is a possible increase in bed scour. Bed scour is an important attribute in EDT because of its potential effect on the survival of salmonid eggs deposited in redds. While it is reasonable to expect that the depth and frequency of bed scour would increase with increases in winter flow, there is no way to quantitatively estimate the change. To capture the effect in the two alternative future climate conditions, it was hypothesized that 1) bed scour would increase in proportion to the increase in peak flow, and 2) the increase in bed scour would be greatest in higher gradient stream reaches. Specifically, bed scour in the EDT model was assumed to increase in proportion to the change in peak flow in reaches with a gradient greater than 0.4%. The result is that bed scour was increased in most reaches upstream of the South Fork Chehalis River but not in most of the lower gradient reaches downstream. Temperature changes in the Low Climate Change and High Climate Change scenarios were based on projections of change temperature from Snover et al. (Snover et al. 2013) for years 2020 and 2080, respectively (Table 5.5), and applied to the modeled temperatures in EDT.

All quantitative modeling of flow and width (HEC-RAS) and temperature used in EDT analyses of water retention alternatives was focused on the mainstem reaches below the proposed dam site. For conditions in the tributaries, HEC-RAS model output was not available. Because climate change will affect the entire Chehalis basin, it was necessary to include changes to tributary conditions. In the absence of any means to quantitatively project flow, channel width, temperature, and other factors in the tributaries under the alternative future conditions, the proportional changes to attributes in the mainstem that are based on quantitative analysis were applied to the tributary reaches as well. As a result, both future alternative conditions assume changes in the tributary stream reaches in addition to changes in the mainstem Chehalis River.

It is important to caveat this procedure by stating that these two alternative futures do not represent a prediction of future condition nor are they based on downscaling of any particular climate model. The intent was to evaluate alternative futures that are consistent with projections of future climate in western Washington. Also, the changes in the tributary reaches are considered to be much more speculative than the assumed changes in the mainstem reaches due to the lack of quantitative data.

Table 5.4
Summary of Changes Related to Alternative Future Conditions Modeled in EDT

ATTRIBUTE	AREA	LOW CLIMATE CHANGE	HIGH CLIMATE CHANGE	SOURCE
High Flow	Mainstem below dam site	Increase	Increase	HEC-RAS
Low Flow	Mainstem below dam site	Decrease	Decrease	HEC-RAS
Winter Channel width	Mainstem below dam site	Increase	Increase	HEC-RAS
Summer Channel width	Mainstem below dam site	Decrease	Decrease	HEC-RAS
Temperature Max winter	Mainstem below dam site	Increase based on Snover et al. 2013 in Table 5.5		Snover et al. 2013
Temperature Max summer	Mainstem below dam site			
Bed Sour	Mainstem below dam site	If gradient is >0.004 then increase rating by proportion Flow High increases, else no change.	If gradient is >0.004 then increase rating by proportion Flow High increases, else no change.	Hypothesis
High Flow	Tributaries	Increase	Increase	Hypothesis
Low Flow	Tributaries	Decrease	Decrease	Hypothesis
Winter Channel width	Tributaries	Increase	Increase	Hypothesis
Summer Channel width	Tributaries	Decrease	Decrease	Hypothesis
Temperature Maximum winter	Tributaries	Change in proportion to mainstem changes in Table 5.5		Snover et al. (2013)
Temperature Maximum summer	Tributaries			
Bed Scour	Tributaries	If gradient is >0.004, then increase rating by proportion High Flow increases, else no change.	If gradient is >0.004, then increase rating by proportion High Flow increases, else no change.	Hypothesis

Table 5.5
Assumed Changes in Water Temperature in the Chehalis Based Under the Alternative Futures Scenarios

MONTH	LOW CLIMATE CHANGE		HIGH CLIMATE CHANGE	
	UPPER	LOWER	UPPER	LOWER
January	15%	14%	48%	46%
February	19%	18%	50%	46%
March	14%	11%	43%	33%
April	9%	8%	28%	23%
May	6%	6%	20%	17%
June	8%	7%	24%	22%
July	8%	7%	23%	21%
August	9%	8%	26%	23%
September	8%	7%	27%	25%
October	9%	8%	32%	28%
November	11%	10%	36%	34%
December	13%	15%	44%	49%

5.3.1.2 SHIRAZ

In SHIRAZ, the analysis area was limited to the mainstem Chehalis River. SHIRAZ is a population simulation model that can be run over a user-defined period of time with inputs varied on a year-to-year basis. In the SHIRAZ climate change effects analysis, model inputs on habitat quantity and quality were adjusted based on the projected changes in the 2040s associated with A1B greenhouse gas emissions scenario. The following scenarios were run in SHIRAZ to inform the climate change analysis:

- Mainstem conditions assuming climate change
- Mainstem conditions assuming climate change and water retention alternatives (separate runs for FRO and MPD Alternatives)

5.3.1.3 PHABSIM, HABITAT SUITABILITY INDICES, AND CORRELATIVE MODELS

As with other aspects of the analysis, the effects of climate change for those species where appropriate data were available was assessed for Other Fish and Non-fish Species using the PHABSIM, and HSI. Correlative models, which were based on the inundation index, could not model climate change because of ambiguity in projecting the changes in mean monthly flows and data needed to confidently run the models was unavailable. The projected changes described previously associated with the A1B greenhouse gas emissions scenario were assessed to address the following:

- Effects on the quantity, location, connectivity, and timing of suitable habitat conditions related to specific life history requirements
- Projected changes in temperature relative to identified temperature preferences or even lethal thresholds for species
- The magnitude of projected changes are averages, but the qualitative portion of the analysis should also be informed by the variability around the averages and the extreme ends of the projected range of conditions
- Changes in species competitive and predatory interactions possibly resulting from greater overlap in distribution

For PHABSIM climate change analyses, only the months of July, August, and September were modeled. Only summer months were modeled because winter flows frequently exceed the calibration range of the model, preventing confident estimation of the changes in WUA. Discharge from the FRO Alternative for these summer months was considered to be similar to the baseline, so for PHABSIM climate change analyses, only the MPD Alternative was assessed.

PHABSIM is a tool for evaluating how different stream flows will effect aquatic habitat. If flow (timing, duration, and magnitude) can be projected, PHABSIM can be used to compare habitat available at different flows within the range of flows for which the PHABSIM is calibrated, which generally excludes freshet (flood) flows. The peak flows from Table 5.3 are outside the range of extrapolation of typical PHABSIM models based on their calibration; however, percent reductions in the daily average streams flow for the months of July (16.8%), August (26.0%), and September (18.4%) in the 2080s were incorporated into PHABSIM to estimate potential changes in WUA of habitat for several species. Lastly, although habitat change is measured as WUA, WUA does not encompass all aspects of habitat required by a particular species and represents only an estimate of habitat change.

Flows for each reach were obtained from HEC-RAS daily flows modeled for comparable cross sections of the Chehalis River for 12 months of a normal WY (WY 2008, from October 2007 to September 2008). The evaluation focused on changes in daily average flows during the months of July, August and September (Table 5.2) because variability in flow is minimal in summer and median flow is most informative then. Notably, this timeframe does excludes all species migration and spawning periods; however, given the limitations of PHABSIM in evaluating relatively short, elevated flow events, as well as the increased variability in flow during other months (which can often exceed the calibration range of the model), the summer months focus was appropriate. Other months will be discussed in text, but additional analysis of these months is needed, preferably on a daily, rather than a monthly, time step. Although spring spawning WUA was not directly assessed, changes in WUA in July were viewed as a possible surrogate for spring spawning WUA. This assumption requires validation.

Although Table 5.1 lists projected water temperature increases, tools incorporating temperature into WUA outputs are only now being developed and tested. Temperature and peak flow can also influence when habitat is used, but assessing them was beyond the scope of this study. Nonetheless, they represent an important gap that should be addressed in future efforts and are discussed in the companion *Data Gaps Report*.

Assessing potential effects of sea level rise from climate change on aquatic species in the lower Chehalis River was hindered by a lack of information on species distribution and habitat use in these areas. Therefore, the potential effects were evaluated using correlative methods based on general habitat use information.

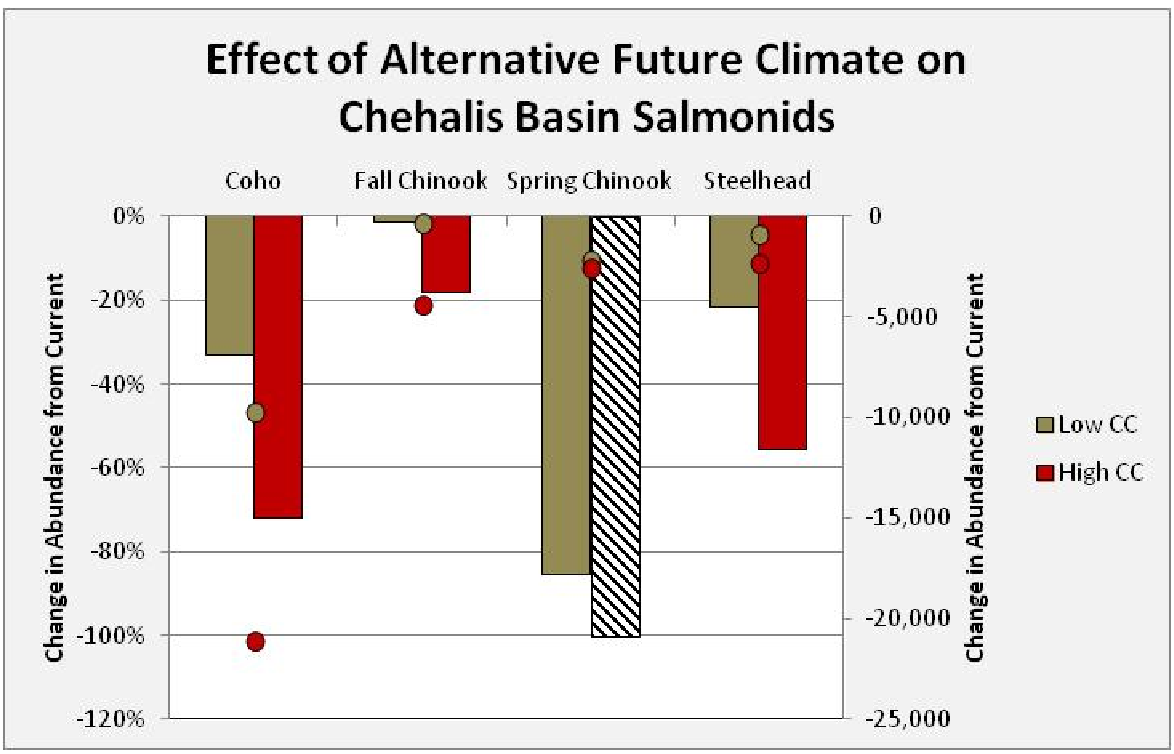
5.4 Discussion of Results

5.4.1 ECOSYSTEM DIAGNOSIS & TREATMENT

The change in salmon production at the basin scale for each species under the alternative future climate conditions is shown in Figure 5.8. The alternative future conditions had their greatest effect on spring-run Chinook salmon and their least effect on fall-run Chinook salmon. Under the High Climate Change scenario, spring-run Chinook salmon were extirpated from the Chehalis basin. Under the Low Climate Change scenario, spring-run Chinook salmon were substantially reduced. The effects were primarily the result of assumed increases in summer water temperature in the alternative future conditions, which was applied proportionately to all sub-basins in the system. Adult spring-run Chinook must survive through the summer prior to spawning in the fall and are constrained in the model by current summer water temperatures (see Figure 4.23). The increase in summer temperature under the High Climate Change scenario reduced adult survival to the point of extirpation. As with the benefits to spring-run Chinook salmon associated with the MPD Alternative due to cold water releases from the dam, these effects to spring-run Chinook salmon from under the future climate conditions are predicated on the assumption that the fish are holding prior to spawning in the areas where the effects are projected to occur. However, the available information on spring-run Chinook salmon holding locations is insufficient to be certain whether these salmon will be exposed to the full effect of this modeled scenario or have access to and utilize thermal refugia, which would reduce the effects of future climate scenarios on this run of salmon.

Fall-run Chinook salmon are expected to be the least effected by future changes in climate because, in general, they spend less time in the Chehalis system and are less affected by freshwater conditions compared to the other salmonids analyzed using EDT (and SHIRAZ). They enter the river in the fall just prior to spawning and emigrate the following spring; their major residency in the Chehalis system is in the winter when temperature effects of climate change would be least. Coho salmon and winter-run steelhead spend appreciable time in freshwater (1 year for coho salmon, 2 years for winter-run steelhead), but do not have the pre-spawning survival bottleneck of spring-run Chinook salmon. Also, coho salmon and winter-run steelhead are distributed higher in the system where temperature and flow changes under the alternative future conditions were more moderate than in lower stream reaches.

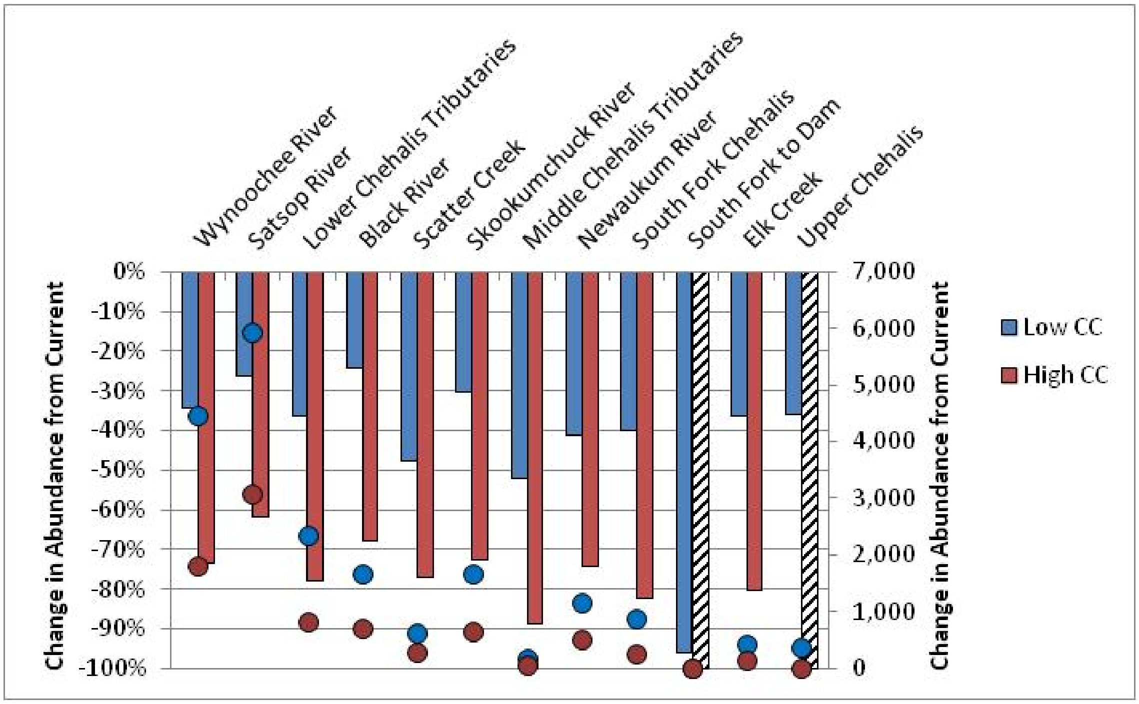
Figure 5.8
Basin-wide Effects of Alternative Climate Conditions on Chehalis Basin Salmonids



Note: Cross hatching indicates extirpated species. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

At the sub-population scale, individual coho salmon populations showed a range of effects to the alternative future conditions (Figure 5.9). Under the Low Climate Change scenario, the abundance of all populations was reduced by approximately 45% relative to current conditions, especially in the mainstem reaches and especially, the South Fork to Dam reach. Under the High Climate Change scenario, the South Fork to Dam and upper Chehalis River populations were extirpated due to a combination of higher water temperature and increased bed scour associated with higher winter flow.

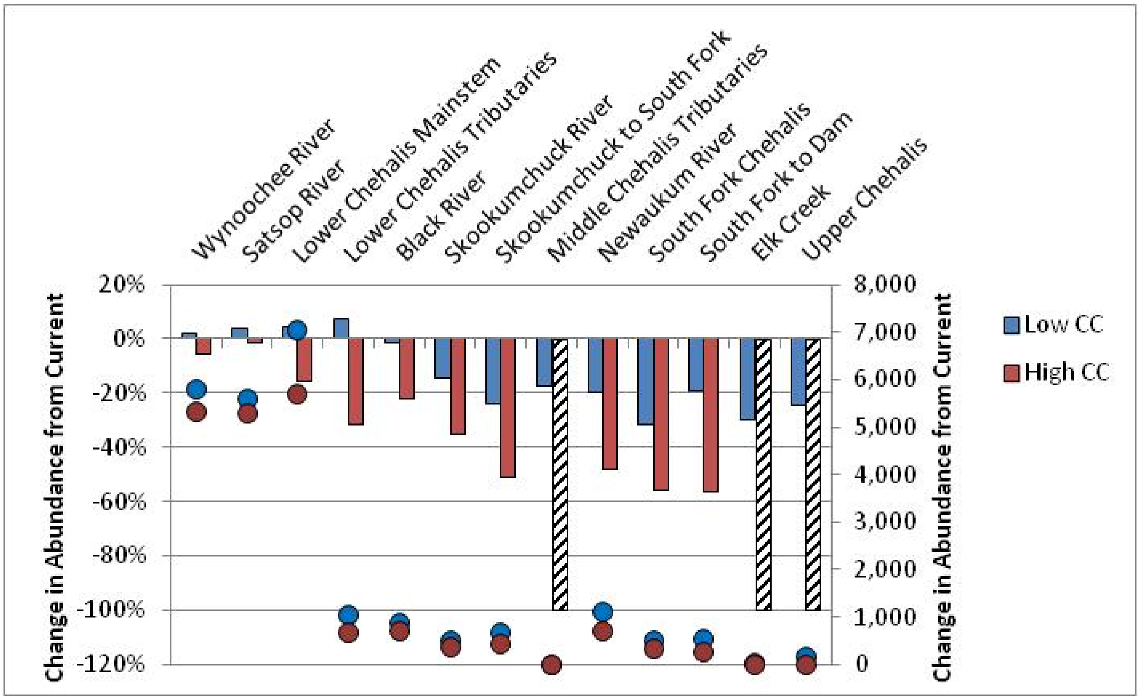
Figure 5.9
Population-level Effects of Alternative Future Conditions on Chehalis Basin Coho Salmon



Note: Cross-hatching indicates extirpated populations. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

At the basin scale, fall-run Chinook salmon showed the least detrimental effects of the alternative future conditions. However, at the sub-population scale, the effects to some populations were substantial (Figure 5.10). Under the Low Climate Change alternative, most populations were reduced by approximately 20%. Some lower river populations actually showed an increase in abundance under the Low Climate Change alternative, due to an increase in winter flows and the resulting wider wetted channel width in the lower mainstem. Under the High Climate Change scenarios, fall-run Chinook salmon were extirpated from the Middle Chehalis Tributaries, Elk Creek, and the upper Chehalis populations (Figure 5.10).

Figure 5.10
Population-level Effects of Alternative Future Conditions on Chehalis Basin Fall-run Chinook

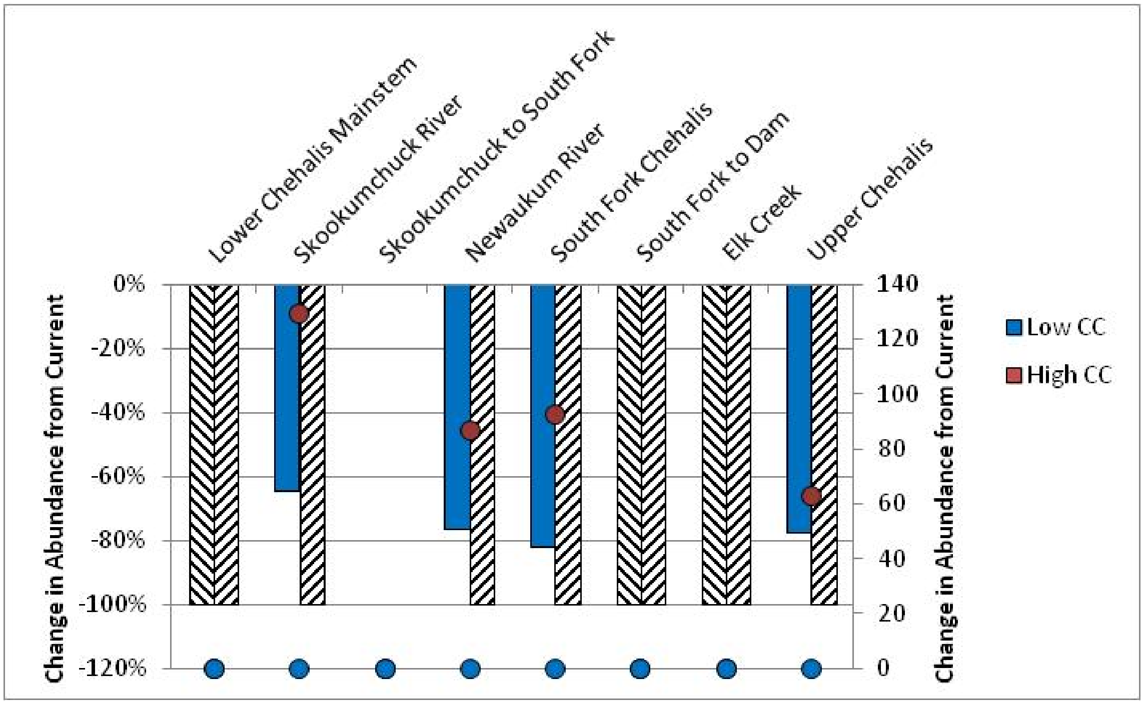


Note: Cross-hatching indicates extirpated populations. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

At the sub-population scale, individual spring-run Chinook salmon populations displayed large effects to the alternative future conditions modeled (Figure 5.11). Under the Low Climate Change scenario the lower Chehalis Mainstem, Elk Creek and South Fork to Dam populations were extirpated, and other populations were reduced relative to current levels. Under this alternative, spring-run Chinook salmon production was confined to the Skookumchuck, Newaukum, South Fork, and upper Chehalis areas where temperatures are more moderate compared to downstream locations. These conditions appeared to create refugia for this species in the basin.

Under the High Climate Change scenario, all spring-run Chinook salmon populations modeled were extirpated (Figure 5.11). It is important to clarify that this result indicates that habitat potential for spring-run Chinook salmon in the basin under this condition is reduced to zero. In the model, it was assumed that the fish remain in these areas and do not migrate to cooler tributaries. In reality, if this condition were to materialize, there might be years where conditions were more benign and/or salmon may seek refuge in cooler tributaries and spring-run Chinook salmon might survive. Overall, the analysis indicated that the species could not be sustained without additional measures under the High Climate Change condition. The lack of change to the Skookumchuck to South Fork population reflects a lack of any spring-run Chinook salmon residing in this reach of river in the model, based on WDFW survey information.

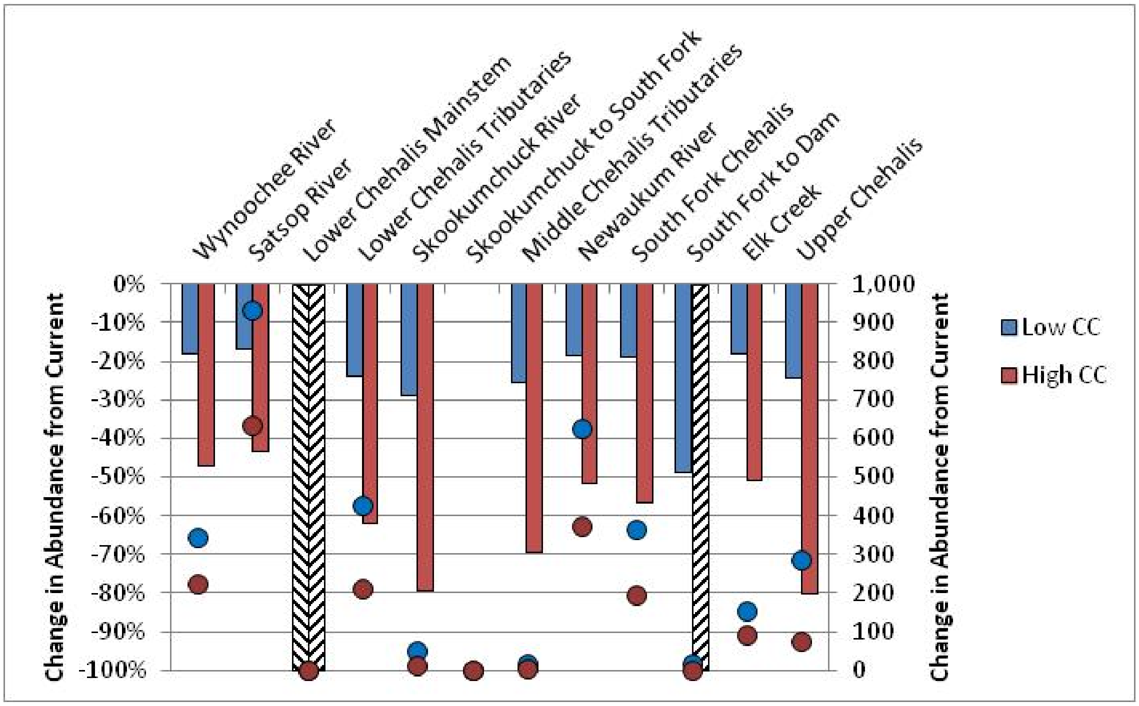
Figure 5.11
Population-level Effects of Alternative Future Conditions on Chehalis Basin Spring-run Chinook



Note: Cross-hatching indicates extirpated populations. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

At the sub-population scale, individual winter-run steelhead populations were also substantially affected by the alternative climate change conditions (Figure 5.12). The lower Chehalis mainstem population was extirpated under both climate alternatives while under the High Climate Change scenario the South Fork to Dam population was also extirpated.

Figure 5.12
Population-level Effects of Alternative Future Conditions on Chehalis Basin Winter-run Steelhead



Note: Cross-hatching indicates extirpated populations. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

5.4.2 SHIRAZ

Under climate change, estimated numbers of mainstem adult spring-run Chinook salmon, winter-run steelhead, and coho salmon population declined but the magnitude of the decline varied among species (Figures 5.13 through 5.15). For spring-run Chinook salmon, the potential effects of climate change were estimated to reduce median returns to zero (extirpated). The median number of winter-run steelhead was estimated to decrease by 62% with climate change compared to existing conditions. The median number of coho salmon was estimated to decrease by 5% with climate change compared to existing conditions.

Figure 5.13
Estimated Number of Spring-run Chinook Salmon Spawners with Climate Change

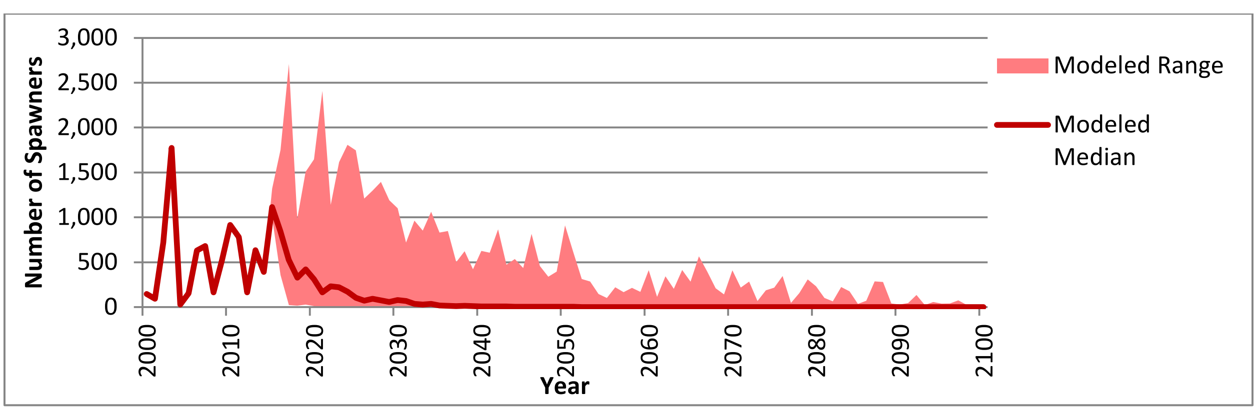


Figure 5.14
Estimated Number of Winter-run Steelhead Spawners with Climate Change

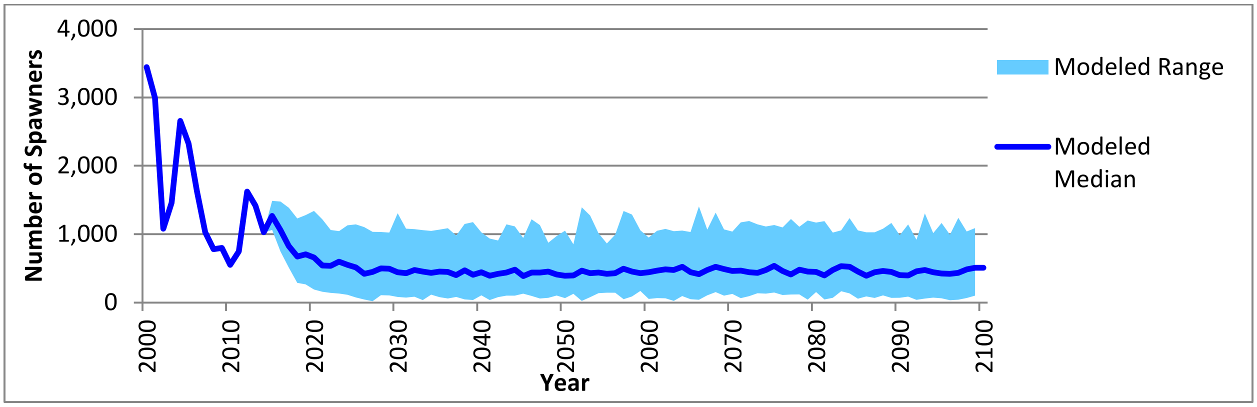
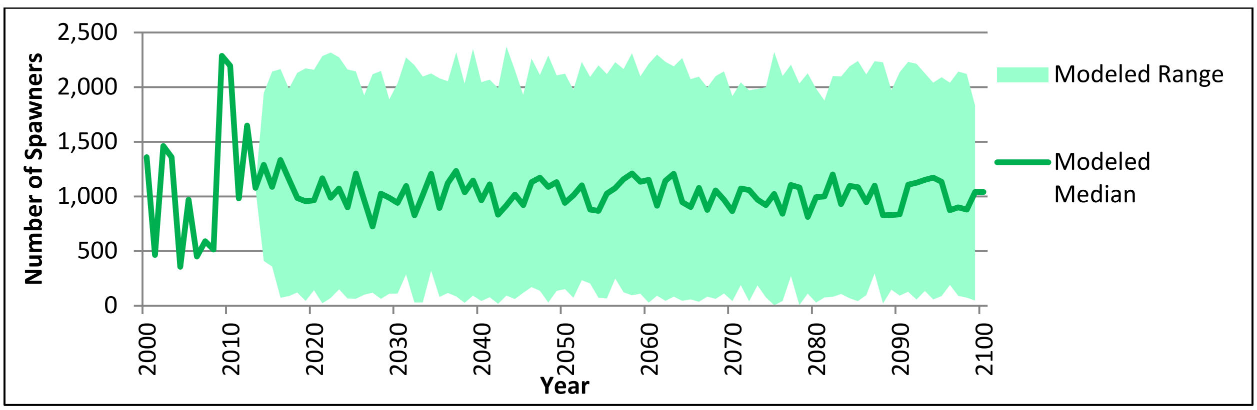


Figure 5.15
Estimated Number of Coho Salmon Spawners with Climate Change



5.4.3 PHABSIM AND HSI ANALYSES

The following sections summarize the effects of climate change on selected Other Fish and Non-fish Species, reflected as changes in habitat (measured as WUA) for the summer months (July through September). This modeling was based on projections for the A1B greenhouse gas emissions scenario, which estimates that summer low flows will decrease by 16.8% in July, 26.0% in August, and 18.4% in September (Table 5.2). These moderately large projected decreases in flow also resulted in flows for the Newaukum to Skookumchuck reach being outside the calibrated range of the PHABSIM model and changes in WUA could not be estimated for this reach. Unless otherwise indicated, individual species data presented reflect changes to combined spawning and rearing habitat.

5.4.3.1 PACIFIC LAMPREY

The projected decreases in summer low flows associated with climate change are estimated to generally increase spawning and rearing habitat from 7.1% to 30.2% for Pacific lamprey (Table 5.6).

Table 5.6
Hydraulic Habitat (WUA) Response to Projected Decreases in Summer Stream Flow by Climate Change from Current (Baseline) Conditions for 2080

SPECIES	MAIN CHANNEL				
	PE ELL TO ELK CREEK	ELK CREEK TO SOUTH FORK	SOUTH FORK TO NEWAUKUM	NEWAUKUM TO SKOOKUMCHUCK	SKOOKUMCHUCK TO PORTER
Pacific lamprey	7.1%	30.2%	11.9%	NE	13.4%
Largemouth bass	NA	31.1%	17.2%	NE	19.6%
Smallmouth bass	NA	9.6%	9.7%	NE	9.0%
Speckled dace - rearing only	6.3%	6.0%	7.4%	NE	10.2%
Largescale sucker	15.9%	9.2%	4.7%	NE	5.8%
Mountain whitefish	-25.9%	-24.2%	-25.2%	NE	-19.9%
Western toad – rearing only	1.2%	16.5%	NA	NA	NA

Notes: NA = Species not recorded in reach; NE = Not able to estimate due to flows outside of model calibrated range; Changes in spawning and rearing are combined unless otherwise indicated.

5.4.3.2 LARGEMOUTH BASS

Largemouth bass is a lentic (stillwater)-adapted species also tolerant of warm water (Wydoski and Whitney 2003). The combination of reduced summer flows and warmer temperatures would generally be favorable to largemouth bass. Indeed, the projected decreases in summer low flows associated with climate change are estimated to generally increase spawning and rearing habitat for largemouth bass from 17.2% to 31.1% (Table 5.6).

5.4.3.3 SMALLMOUTH BASS

Smallmouth bass is more lotic-adapted (i.e., flowing water) than largemouth bass, and also more tolerant of colder water temperatures (Wydoski and Whitney 2003). Therefore, the projected decreases in summer low flows associated with climate change are not expected to be as favorable to smallmouth bass as largemouth bass. In particular, increases of 9.0% to 9.7% with climate change over the current baseline were estimated (Table 5.6).

5.4.3.4 SPECKLED DACE

Speckled dace is a habitat generalist that occurs over a broad geographic range (Wydoski and Whitney 2003); given the diversity of temperatures encountered over this range, may be expected to be somewhat tolerant of temperature change. The projected decrease in summer low flows associated with climate change is estimated to generally increase speckled dace spawning and rearing habitat from 6.0% to 10.2% (Table 5.6).

5.4.3.5 LARGESCALE SUCKER

As noted previously, largescale sucker habitat in PHABSIM was modeled with an HSI that may not be suited to standard application of PHABSIM, potentially underestimating its suitable habitat. For that reason, as well as their ecological significance, habitat for mountain whitefish was also modeled. The projected decrease in summer low flows associated with climate change over the current baseline is estimated to generally increase largescale sucker spawning and rearing habitat from 4.7% to 15.9% (Table 5.6).

5.4.3.6 MOUNTAIN WHITEFISH

Mountain whitefish often co-occurs in mixed schools with largescale sucker, and has a high ecological significance since this species is often the largest contributor to fish biomass in western Washington rivers (Wydoski and Whitney 2003). The projected decrease in summer low flows associated with climate change over current baseline was estimated to uniformly decrease mountain whitefish spawning and rearing habitat from 19.9% to 25.9% for mountain over all modeled reaches (Table 5.6).

5.4.3.7 CHUM SALMON

Chum salmon do not occur in the Chehalis River basin during summer; however, if winter flows were to become flashier as a result of climate change, the greatest risks to chum salmon are scouring of eggs, limitation of their access to very small tributaries to spawn, and subsequent stranding of eggs.

5.4.3.8 WESTERN TOAD

The projected decrease in summer low flows associated with climate change over current baseline is estimated to increase spawning and rearing habitat from 1.2 to 16.6% for western toad over all modeled reaches (Table 5.6). However, non-aquatic stages of western toad use upland habitats that climate change may affect differently from their aquatic breeding habitat, so the overall response of western toad to climate change is uncertain.

5.4.4 CORRELATIVE ANALYSIS

The inundation index described in Section 4 quantifies the change in acres of inundation, which relates to the amount of habitat available to species occupying off-channel habitats because these habitats are created and maintained by inundation of the floodplain. The decreases in inundation anticipated under proposed dam alternatives translate into decreases in habitat for off-channel species, which must also be considered under the predicted changes in climate over the next 100 years.

Tables 5.1, 5.2, and 5.3 show predicted changes in temperature, average monthly flow, and peak flows under the A1B greenhouse gas emissions scenario, respectively. Water temperature is predicted to increase from 1.4 to 3.1°C (37.6°F) by year 2099, peak flows are predicted to increase by up to 15%, and low flows are predicted to decrease by 3% by the 2080s. Additionally, increases in heavy rainfall events, extreme flow events, and periods that are abnormally wet and abnormally dry are anticipated for Washington State.

The effects of warming temperature on the temperature profile in off-channel habitats need to be considered. Currently, information on off-channel habitat seasonal temperature profiles is entirely lacking. Those habitats, in many cases, are warmer than in-stream aquatic habitats. Predicted warmer profiles could be exacerbated by regularly decreasing flow connections with these habitats under dam operations. Species such as the northern red-legged frog, which possess the lowest critical thermal maximum for their early embryonic stages of any North American frog (early stage embryos die at 21°C and appeared stressed at 20°C [68°F]; Licht 1971), may experience a contraction of the already relatively short winter period in which they may breed. A secondary complication is that generally warming seasonal temperature profiles will likely favor the suite of warm water non-native predators that has a potentially negative effect on many native Fish and Non-fish Species utilizing off-channel habitats. As interactions between the temperature profile, non-native aquatic predators, and responses of individual native species are likely, the uncertainties associated with specific outcomes are simply too great to make any reasonable predictions without some basic physical data on current conditions in off-channel habitats and the frequency and magnitude of their seasonal connectivity to the remainder of the aquatic system.

Changes in flow must also be considered. Predicted increases in winter flows could cause an increase in the level of floodplain inundation, while decreases in summer flows have the potential to further decrease connectivity during summer months. These changes could alter the rearing and breading habitats for species in the off-channel areas including species that are sensitive to flow, including Olympic mudminnow (Henning et al. 2007) and all fish species on this habitat guild, which are susceptible to stranding when low summer flows disconnect off channel habitat.

5.4.5 POTENTIAL EFFECTS OF SEA LEVEL RISE

Sea level rise will modify the estuarine footprint in a manner that may influence the suite of organisms capable of occupying some off-channel habitats in the estuary area of the lower Chehalis. The effects of sea level rise could be positive or negative. For example, if movements among areas are restricted under contemporary conditions, sea level may aid access to habitats. Increased flood frequency and flood level due to climate change, along with sea level rise, may also increase access to habitats. In contrast, sea level rise could further isolate fish populations inhabiting marshes on the north shore of Grays Harbor. It could also allow salt water to extend further upstream, which could affect amphibian species, whose eggs die when salinities exceed 4.5 parts per thousand.

5.5 Discussion of Results

5.5.1 EFFECTS OF CLIMATE CHANGE ON SALMON

Based on EDT, both future climate change scenarios effected all salmon species at the basin-wide scale. As expected, the High Climate Change scenario resulted in greater effects than did Low Climate Change. The alternative future conditions had their greatest effect on spring-run Chinook salmon and the least effect on fall-run Chinook salmon. Under the High Climate Change scenario, spring-run Chinook salmon were extirpated from the Chehalis basin and were substantially reduced under the Low Climate Change condition. The effects were primarily the result of assumed increases in summer water temperature in the alternative future conditions, which was applied proportionately to all sub-basins in the system. Across all species and sub-populations, the Low Climate Change scenario resulted in a total of four populations being extirpated, compared to a total of 14 under the High Climate Change scenario.

Based on SHIRAZ model studies, the median number of salmon in the mainstem Chehalis River was estimated to decrease from 5% (coho salmon) to 100% (spring-run Chinook salmon) with climate change compared to existing conditions.

5.5.2 EFFECTS OF CLIMATE CHANGE ON OTHER FISH AND NON-FISH SPECIES

Results of PHABSIM analyses estimate that climate change will have a variable but positive effect on Pacific lamprey, largemouth bass, smallmouth bass, speckled dace, and largescale sucker spawning and rearing habitat during summer. For mountain whitefish, climate change greatly reduced both spawning and rearing habitats in all reaches modeled (from Pe Ell to Porter). The projected decrease in flows associated with climate change were also estimated to increase spawning and rearing habitat for western toad over modeled reaches.

6 Combinations of Alternatives

Variability and uncertainty associated with model outputs are key aspects of interpreting model results. While the authors recognized the shortcomings of the current study and identified ways to address them in the future in the companion *Data Gaps Report*, it must be noted that quantifying the variability associated with model outputs was not possible for most analyses. Thus, most values presented throughout this report imply there is a certain level of precision associated with a value, but without accompanying estimates of variance associated with each estimate the impressions the values provide are not bounded by any real measure of uncertainty.

The aforementioned concerns about variability and uncertainty associated with model studies become compounded when individual scenarios are combined to inform their potential combined effect on aquatic species. Authors of this report had no real means to characterize the added variability and uncertainty associated with assumptions about one alternative being combined with assumptions about another alternative. Therefore, it is important to recognize that while the results in the following sections were developed to provide trends in how combinations of alternatives might affect species relative to single alternatives and other combinations, any variability associated with these results has not been characterized at this stage of analyses.

6.1 Habitat Enhancement and Water Retention Alternatives

The companion *ASEP* discusses changes to the abundance of the four salmonid species modeled using EDT with habitat enhancements. This section discusses results of analyses where habitat enhancement actions were combined with water retention alternatives.

While analyzing combinations of actions, it is important to keep in mind that synergisms can occur. Synergisms can be positive, meaning that the change resulting from the combination of actions is greater than the sum of the change from each individual action. Synergisms can also be negative, in which case the combination of actions results in a smaller change than the sum of the change from the individual actions (though the effect will generally be greater than the change for any one action by itself). Positive synergisms occur for example when removing a culvert is combined with habitat enhancement such as the addition of large wood below and upstream from the culvert. Removing the culvert by itself increases the capacity of the habitat to produce fish by opening up new habitat, but that habitat is of poor quality because it lacks wood. On the other hand, adding wood without removing the culvert only results in a change to fish abundance from improving habitat quality below the blocking culvert. Removing the culvert and then adding wood upstream and downstream from the culvert increases capacity (i.e., makes more habitat) and productivity (provides greater habitat complexity due to wood), resulting in an overall change in abundance that is greater than the sum of doing either action by itself. Negative synergisms occur when the effect of actions are limited by the total habitat capacity and the restoration potential for the habitat. Negative synergisms can be counter-intuitive but reflect reality: we cannot restore more than the total potential of the habitat. While it might be possible to enhance habitat conditions beyond their intrinsic conditions, these types of actions were not considered in this analysis. Negative synergisms can occur when analyzing wide-spread actions that mainly improve habitat quality (productivity) rather than habitat quantity (capacity), and were considered when interpreting the results reported here.

The combinations of habitat enhancement and water retention alternatives that were analyzed are presented in Table 6.1. Low and High Enhancement Alternatives were created by combining the Low Enhancement Alternatives for non-managed forest areas (NMF) and for managed forest (MF), and the High Enhancement

Alternatives for NMF and MF, respectively. Identical culvert removals were added to both enhancement alternatives.

The High Enhancement options in the actions were then combined with two water retention alternatives, the MPD and FRO50 Alternatives. In adding the two dam scenarios to the enhancement actions, it was assumed that the MPD Alternative would over-ride the enhancement conditions upstream and downstream of the proposed dam. It was assumed, for example, that enhancement actions would not change the temperature of the MPD reservoir and that the temperature below the dam would be the result of the release temperature from the dam rather than the enhancement actions. For combinations involving the FRO50 Alternative, it was assumed that enhancement would affect temperatures below the dam. The NMF 60/75 option changed key attributes such as temperature to a greater degree under the FRO combination than did the MPD Alternative. This affected the relative effects of the combination scenarios compared to the dam alternatives alone.

Table 6.1
Description of Combination Scenarios Analyzed for Chehalis Basin Salmonids

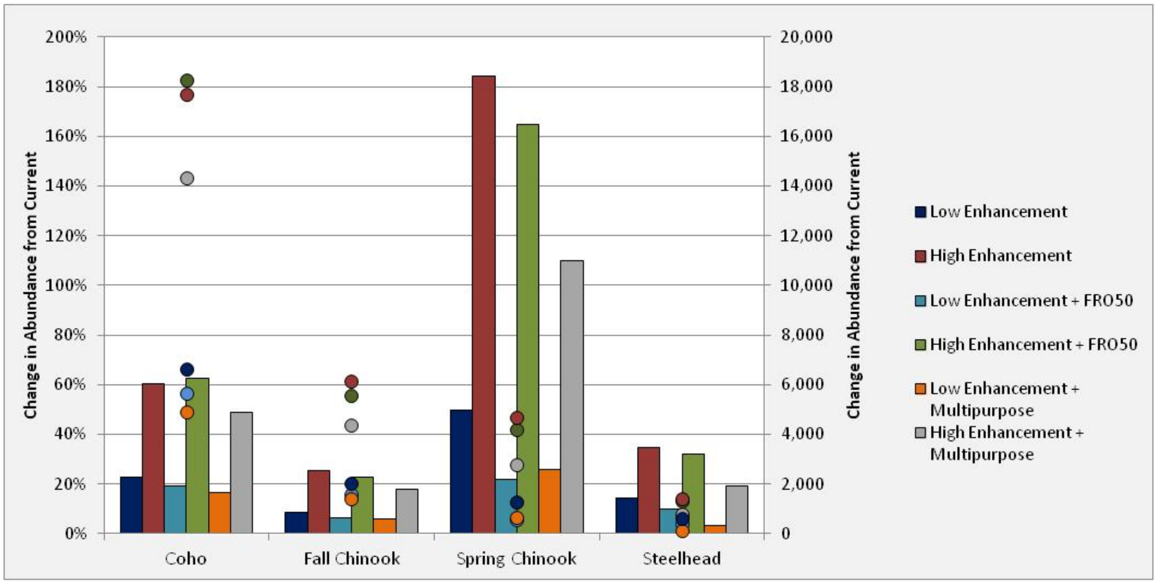
SCENARIO	DESCRIPTION
Low Enhancement + FRO50	NMF 20/50 + MF 20 + Culvert removal + FRO with effects to 50% of the habitat upstream from the dam
Low Enhancement + MPD	NMF 20/50 + MF 20 + Culvert removal + MPD
High Enhancement + FRO50	NMF 60/75 + MF 60 + Culvert removal + FRO with effects to 50% of the habitat upstream from the dam
High Enhancement + MPD	NMF 60/75 + MF 60 + Culvert removal + MPD

Notes: FRO = Flood Retention Only
MF = managed forest
MPD = Multi-purpose Dam
NMF = non-managed forest

Results of the combination scenarios are shown in Figure 6.1. As a proportion of the population, the enhancement measures primarily benefited spring-run Chinook salmon, which was the target of the NMF alternatives and especially affected conditions in mainstem reaches. Spring-run Chinook salmon populations in the EDT model responded positively to reductions in temperature associated with the enhancement alternatives. A surprising result of the combination was that High Enhancement + FRO50 provided a greater benefit to spring-run Chinook salmon and other species than did the High Enhancement + MPD Alternative (Figure 6.1). This is the reverse of the ordering of the two dam alternatives when they were considered alone (when not combined with riparian enhancement). The reason for this difference was the assumption used in the analysis discussed previously in this section of the report.

Numerically, the combination of enhancement and water retention alternatives resulted in the greatest increase in coho salmon (Figure 6.1). The numeric change in the other species was much less, reflecting less change in the case of fall-run Chinook salmon, and much lower level of abundance of spring-run Chinook salmon and winter-run steelhead. Both proportionately and numerically, the proposed flood control alternatives reduced the benefits of riparian enhancement although the resulting abundance was still greater than the abundance under current conditions at the basin-wide scale.

Figure 6.1
Proportional Changes in Chehalis Basin Salmonids from Current Abundance Due to Riparian Enhancements, Culvert Removal, and Flood Retention Alternatives

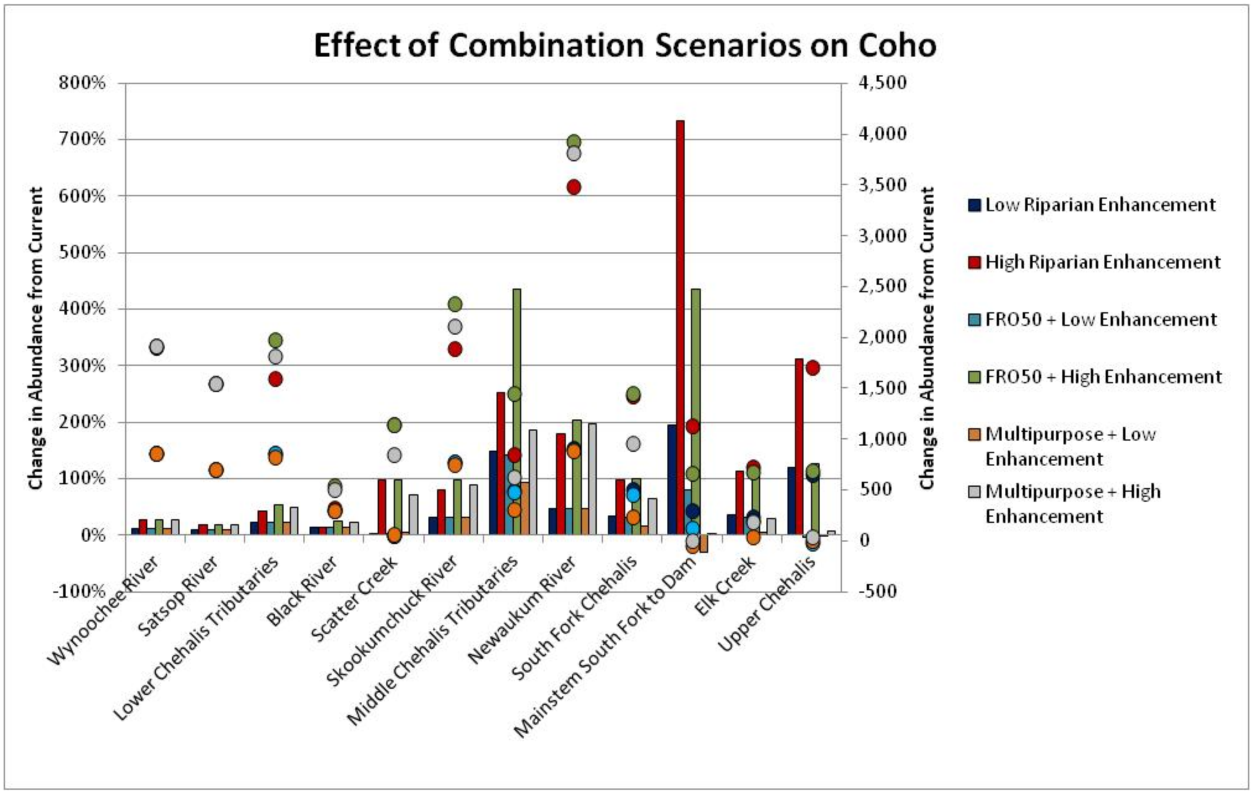


Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

The effect of the combination scenarios on coho salmon populations is shown in Figure 6.2. The FRO50 alternative in combination with High Enhancement provided greater benefits than High Enhancement alone for populations below the South Fork Chehalis River. This was due to an assumed reduction in bed scour below the dam associated with a reduction in flood flows. For mainstem South Fork to Dam, Elk Creek, and upper Chehalis populations, the negative effect of the FRO50 alternative overshadowed the benefits of riparian enhancement under this combination, such that FRO50 plus High Enhancement reduced benefits to coho relative to the High Enhancement scenario alone.

The addition of the MPD Alternative to the High and Low Enhancement alternatives generally reduced the benefits of enhancement alone, especially for the upper basin populations. However, under the MPD Alternative alone, coho salmon population abundance upstream from the dam decreased. Therefore, the enhancement alternatives had an overall positive effect when combined with the MPD Alternative. For the upper Chehalis River coho salmon population, High Enhancement actions moved the effects of the two water retention alternatives from a negative effect on abundance to a strong (FRO Alternative) or slightly positive response (the MPD Alternative). Populations below and including the South Fork generally showed increased abundance when the MPD was combined with High Enhancement. The combination of Low Enhancement and the MPD Alternative reduced coho abundance relative to the current condition in the South Fork to Dam population, and resulted in some increases in other populations below the South Fork Chehalis River.

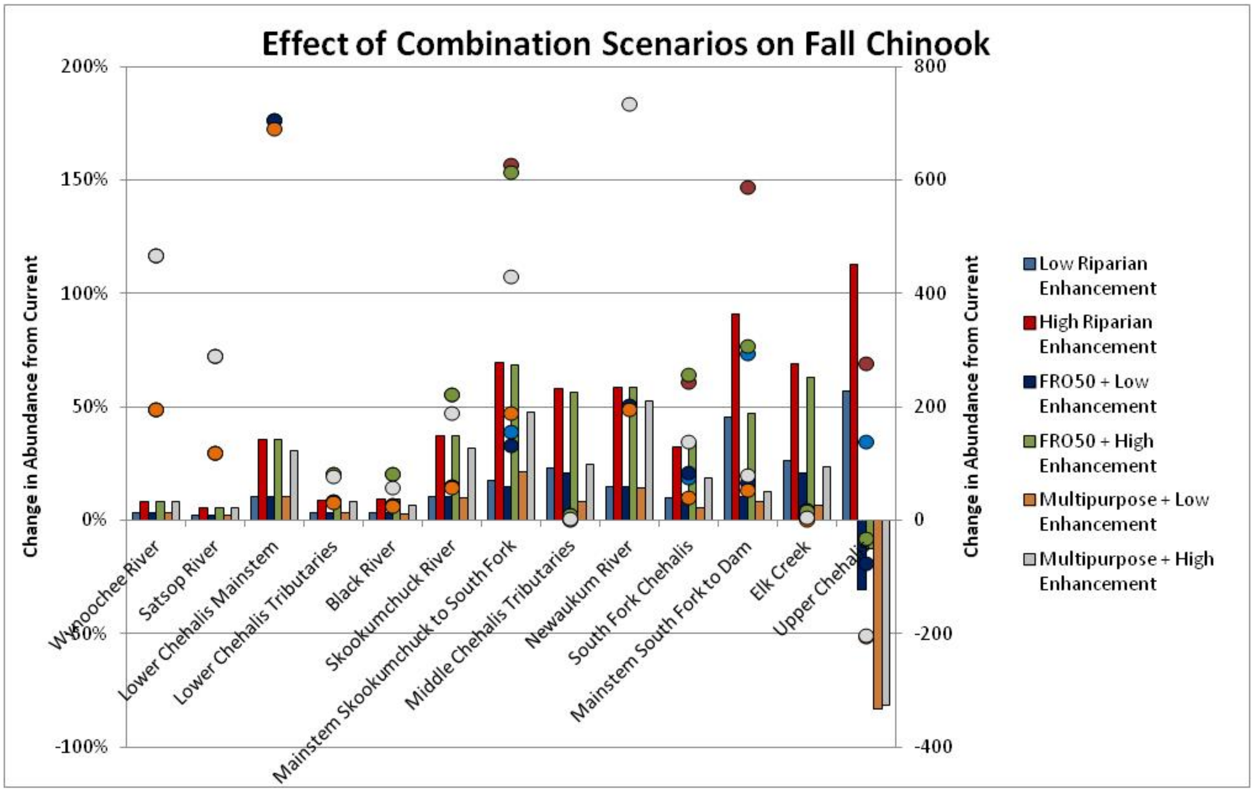
Figure 6.2
Effect of Combination Scenarios on Chehalis River Coho Salmon Populations



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

For fall-run Chinook salmon, the addition of water retention alternatives to the High and Low Enhancement alternatives reduced fall-run Chinook salmon abundance for the upper Chehalis River population (Figure 6.3). Adding dam alternatives to the High and Low Enhancement alternatives generally reduced the benefits of enhancement to populations nearest the dam location, or had little effect on populations further downstream. Enhancement actions generally moderated the negative effects of the water retention alternatives relative to the effect of dam alternatives on fall-run Chinook salmon populations alone.

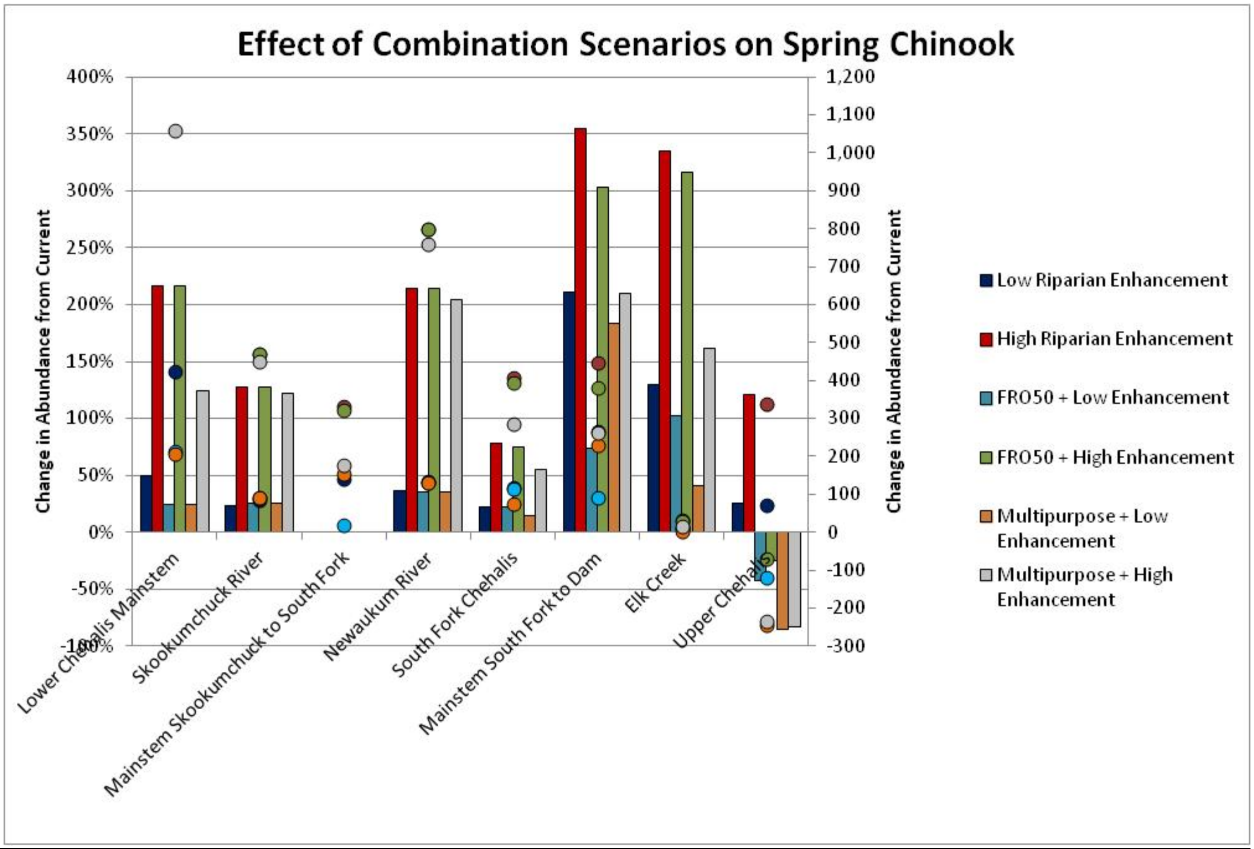
Figure 6.3
Effect of Combination Scenarios on Chehalis River Fall-run Chinook Salmon Populations



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

For spring-run Chinook salmon, the addition of water retention alternatives to the High and Low Enhancement Alternatives reduced spring-run Chinook salmon abundance for the upper Chehalis River population (Figure 6.4). Thus under these combinations, the negative effect of the reservoir associated with the MPD Alternative on the upper Chehalis spring-run Chinook salmon population was only slightly moderated by either riparian enhancement alternative. This is because most of the suitable spring-run Chinook salmon spawning habitat upstream from the dam was in the reaches that were inundated by the reservoir, which eliminated most of the spawning trajectories in the model and so enhancement of the upper Chehalis tributary habitats had little effect on the upper Chehalis River population. Adding dam alternatives to the High and Low Enhancement Alternatives generally reduced the benefits of enhancement to spring-run Chinook salmon populations nearest the dam location, or had little effect on populations further downstream.

Figure 6.4
Effect of Combination Scenarios on Chehalis River Spring-run Chinook Salmon Populations

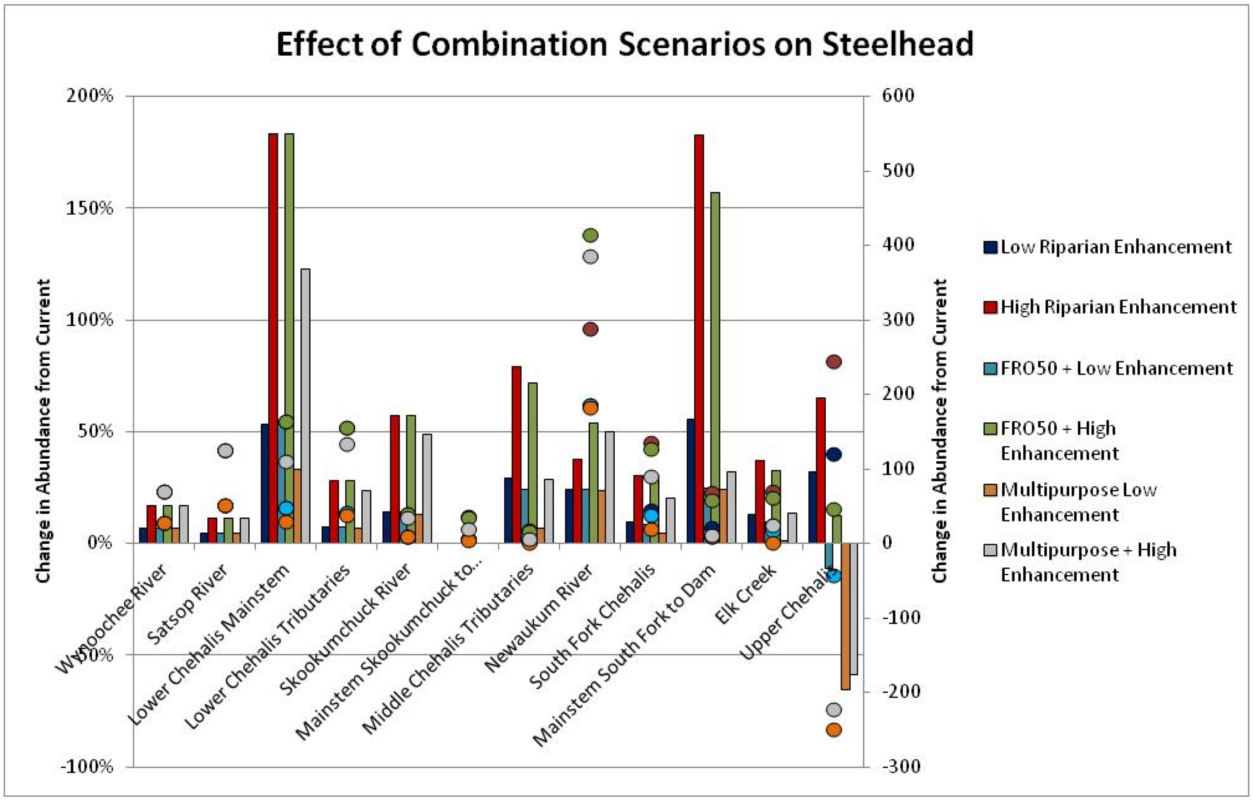


Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

For winter-run steelhead, the addition of water retention alternatives to the High and Low Enhancement alternatives reduced winter-run steelhead abundance for the upper Chehalis River population under three combinations, and increased abundance slightly under the FRO50 and High Enhancement combination (Figure 6.5). In general, adding enhancement alternatives to dam alternatives resulted in only a small reduction in the negative effects of the MPD Alternative alone. The reservoir associated with the MPD Alternative provided no benefit to winter-run steelhead but eliminated all potential spawning within the inundated reaches. On the other hand, the FRO Alternative eliminated a lesser amount of habitat while the remaining habitat was improved by the riparian enhancement, such that there was a greater moderation of the negative effect of the FRO dam on winter-run steelhead in the upper Chehalis when combined with High Riparian Enhancement. Adding dam alternatives to the High and Low Enhancement alternatives generally reduced the benefits of enhancement to spring-run Chinook salmon populations nearest the dam location, or had little effect on populations further downstream.

In the companion *Data Gaps Report*, the need for additional sensitivity analyses using EDT to identify how much of the response to riparian restoration alternatives (and combinations thereof) modeled was from temperature effects versus other attributes is discussed. Other attributes would include, for example, large wood entering the in-stream channel and creating habitat or influencing habitat-forming processes. Understanding the contribution various parameters in the model have on the outcomes will help inform and guide future analyses and restoration efforts.

Figure 6.5
Effect of Combination Scenarios on Chehalis River Winter-run Steelhead Populations



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

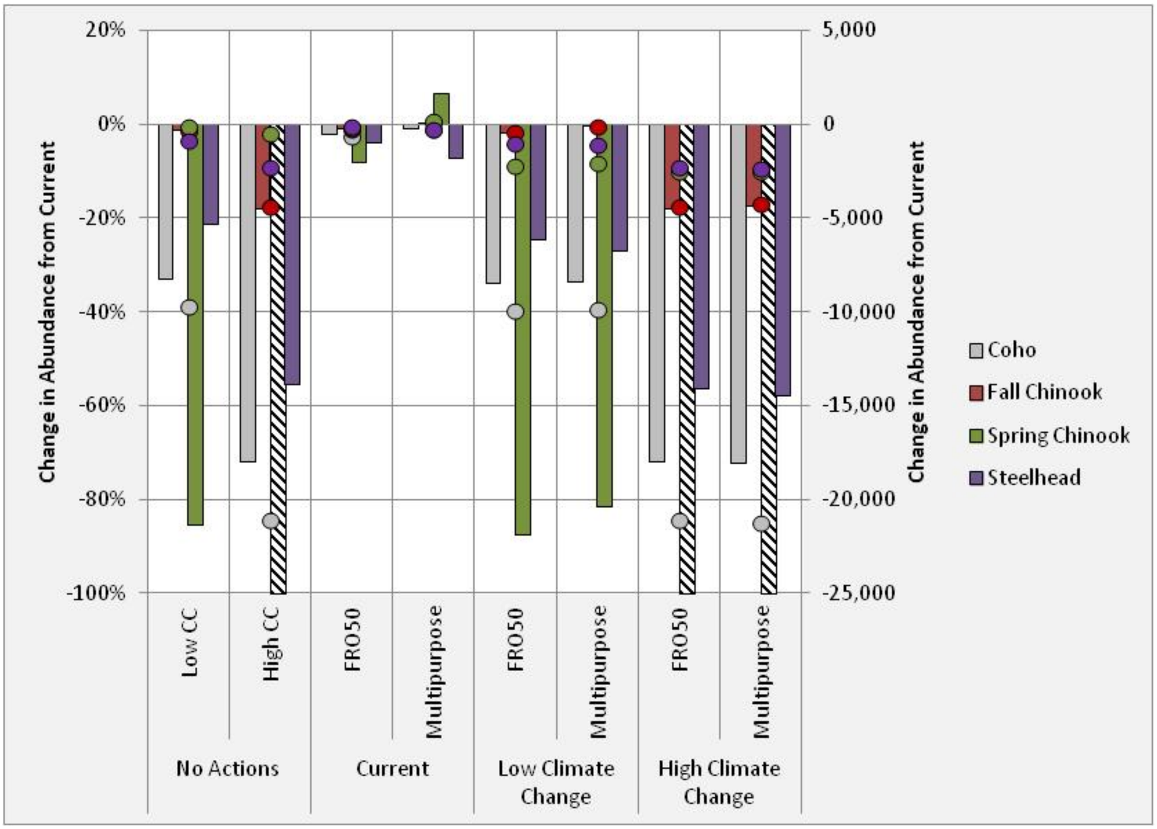
6.2 Water Retention and Climate Alternatives

The methods used to assess changes to the abundance of the four salmonid species modeled using EDT with individual water retention and climate change alternatives are presented above along with the results. To assess the potential interactions among results when water retention alternatives and climate change alternatives are combined, High and Low Climate Change scenarios were combined with water retention alternatives.

6.2.1 RESULTS OF ANALYSIS ON SALMON USING EDT

At the basin scale, the effects of the High and Low Climate Change scenarios were much larger than the effects of flood retention alternatives for all four salmon species. Placing water retention alternatives in the watershed under climate change scenarios resulted in a range of effects on species. Fall-run Chinook salmon showed small changes from the water retention alternatives, whereas for the other species modeled, in general, the water retention alternatives exacerbated the effects of the climate change scenarios on salmon (Figure 6.6).

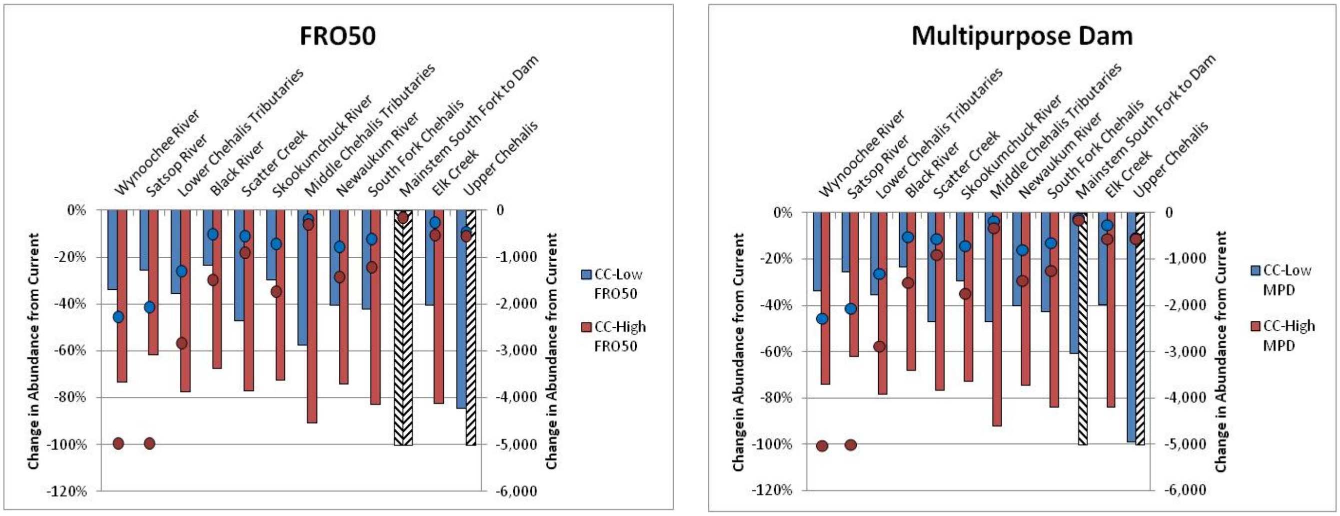
Figure 6.6
Effect of Flood Retention Alternatives on Chehalis Basin Salmon Under Alternative Future Conditions



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition. The cross-hatched bars represent alternatives under which spring-run Chinook salmon were estimated to be extirpated (100% change in abundance).

The water retention alternatives generally exacerbated the effects of the climate change scenarios on coho salmon (Figure 6.7). With Low Climate Change, the South Fork to the Dam population was extirpated under the FRO50 Alternative. This alternative reduced wood delivery and coarsened habitat while temperatures and flow were equal to the base condition. The MPD Alternative reduced the effect of the Low Climate Change scenario on the South Fork to Dam coho salmon population relative to the no-dam situation. In this case, the cooler water from the dam moderated climate change impacts.

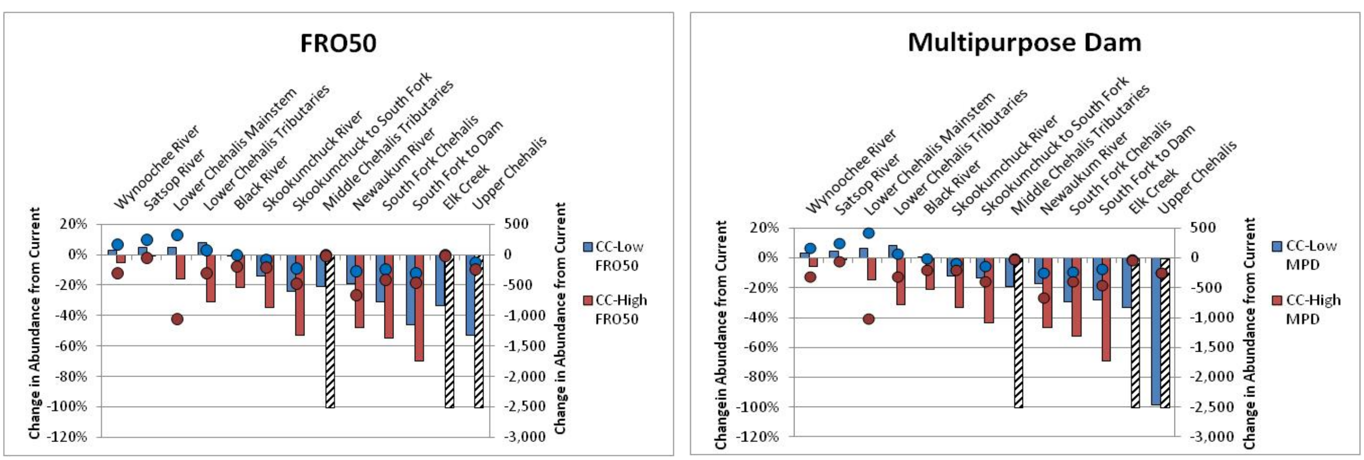
Figure 6.7
Effect of Flood Retention Alternatives on Chehalis Basin Coho Salmon Under Alternative Future Conditions



Note: Cross-hatching indicates extirpated populations. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

The effects of water retention alternatives when combined with alternative future conditions on fall-run Chinook salmon were relatively small (Figure 6.8). No additional populations were extirpated under either dam alternative. However, the upper Chehalis fall-run Chinook salmon population was very nearly extirpated under the combination of MPD and High Climate Change. On the other hand, the MPD Alternative moderated the effects of the High Climate Change condition on the South Fork to Dam population due to the release of cold water from the dam.

Figure 6.8
Effect of Flood Retention Alternatives on Chehalis Basin Fall-Run Chinook Salmon Under Alternative Future Conditions

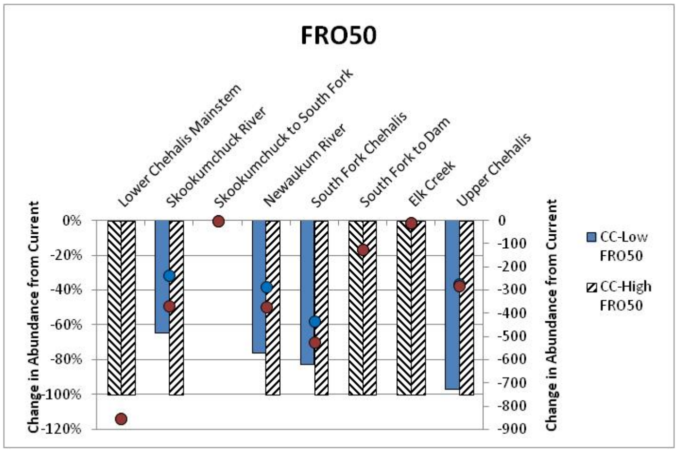


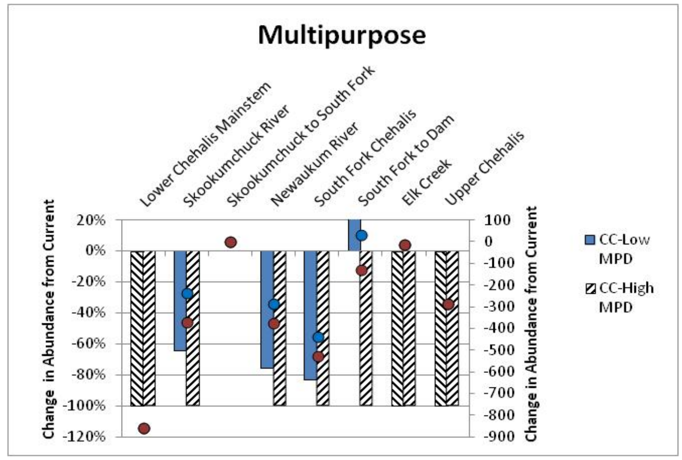
Note: Cross-hatching indicates extirpated populations. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

The FRO50 Alternative had little effect on spring-run Chinook salmon responses to the alternative conditions relative to the no dam situation, except that the condition of the upper Chehalis population worsened under the

Low Climate Change condition and was nearly extirpated (Figure 6.9). The upper Chehalis population was extirpated under the MPD Alternative. The beneficial effect of the cold water releases from the MPD resulted in an increase in the South Fork to Dam spring-run Chinook salmon population relative to the current abundance, although at a much reduced level relative to the increase estimated to occur under current (i.e., without climate change) conditions.

Figure 6.9
Effect of Flood Retention Alternatives on Spring-run Chinook Salmon Under Alternative Future Conditions

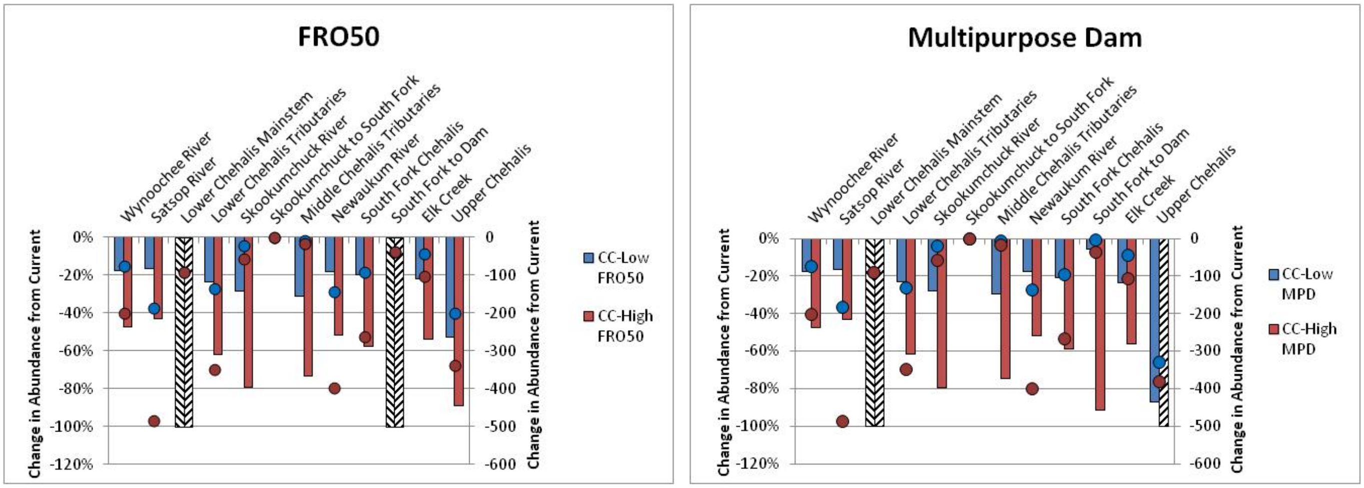




Note: Cross-hatching indicates extirpated populations. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

With the FRO50 Alternative, the South Fork to Dam winter-run steelhead population was extirpated under both alternative climate conditions (Figure 6.10). This alternative had the same flow and temperature condition as the no-dam situation, but also assumed that the dam would reduce large wood delivery and lead to the substrate becoming coarser. The MPD Alternative resulted in extirpation of the upper Chehalis steelhead population under the High Climate Change condition, while this population was reduced by 90% under the Low Climate Change condition. However, as with the other species, the MPD moderated the effect of the alternative future conditions in the South Fork to Dam population due to the release of cold water from the dam.

Figure 6.10
Effect of Flood Retention Alternatives on Chehalis Basin Winter-run Steelhead Under Alternative Future Conditions



Note: Cross-hatching indicates extirpated populations. Bars represent percent change and dots represent numeric change in abundance relative to current condition.

6.2.2 RESULTS OF ANALYSIS ON SALMON USING SHIRAZ

Results of SHIRAZ model studies of climate change and flood retention alternatives for each species compared to the continuation of existing conditions are presented in Table 6.2. For spring-run Chinook salmon, an MPD was estimated to lessen the effects of climate change such that the number of spawners decreased by 49% compared to a 100% decrease in under Climate Change Only (i.e., no dams). This is not surprising given the low abundance of spring-run Chinook salmon in the Chehalis basin, their unique life history that makes adults susceptible to elevated water temperatures prior to spawning, and the benefit releasing cold water from an MPD would have on augmenting flow and cooling water temperatures during the summer holding period. For winter-run steelhead, estimated reduction in number of spawners was 62% with Climate Change Only and when combined with the FRO Alternative, and 49% with the combination of climate change and the MPD Alternative. Coho salmon decreases were estimated increase substantially when water retention alternatives were combined with climate change. Under the combination, mainstem coho salmon populations decreased 44% with a FRO Alternative and 50% with the MPD Alternative, compared to a decrease of 5% under Climate Change Only.

Table 6.2
Estimated Changes to Median Number of Mainstem Chehalis Salmon with Climate Change

SPECIES	CLIMATE CHANGE ONLY	CLIMATE CHANGE WITH FLOOD REDUCTION DAM	CLIMATE CHANGE WITH MULTI-PURPOSE DAM
Spring-run Chinook salmon	-100%	-100%	-49%
Winter Steelhead	-62%	-62%	-49%
Coho salmon	-5%	-44%	-50%

6.2.3 RESULTS OF ANALYSIS ON OTHER FISH AND NON-FISH SPECIES USING PHABSIM AND HSI ANALYSES

Results of PHABSIM analyses indicate that the combination of climate change and operations associated with the MPD Alternative during summer would decrease the extent of positive effect as the result of climate change. Summer low flows under the climate change scenario with operation of the MPD would result in a 2.2 to 9.8% increase in WUA for Pacific lamprey over all reaches examined (Table 6.3).

The effects of climate change and the MPD Alternative on largemouth bass, smallmouth bass, speckled dace, and largescale sucker generally remained positive, though the level varied among reaches. The effects of the combination of climate change and the MPD Alternative on mountain whitefish spawning and rearing habitat were negative and ranged from -10.2% to -15.2%, depending on the reach. Under this combination, spawning and rearing habitat for largemouth bass would maintain the increase predicted as a result of climate change from 5.1 to 13.7% downstream from the dam (Table 6.3). While reduced temperatures associated with operation of the MPD are anticipated to be detrimental to largemouth bass, Table 6.3 data reflect exclusively flow, not temperature effects. Under this combination, spawning and rearing habitat for smallmouth bass remained positive at 3.3 to 6.7% increases compared to the baseline (Table 6.3). Summer low flows under the climate change scenario with operation of the MPD Alternative will generally maintained an increase in spawning and rearing habitat for speckled dace from 2.1 to 7.5% (Table 6.3). Under this same combination, spawning and rearing habitat for largescale sucker would be positive compared to baseline conditions: increasing from 1.8 to 5.5%. For mountain whitefish, operation of the MPD Alternative under climate change was estimated to decrease spawning and rearing habitat from 10.2 to 15.2% (Table 6.3). The apparent differential response between largescale sucker and mountain whitefish likely reflects a combination of the basis of the modeled flow data for the sucker (at the location of the fishes, which for suckers is bottom-dwelling) and the presumed location of flow modeled in PHABSIM (the water column over the fishes).

Water releases from MPD Alternative during summer have the potential to change rearing (and perhaps breeding) habitat for selected species. In particular, western toads breed in habitats that are typical partially or fully isolated from the channel during summer. Water releases during this time frame may result in reduced in-channel for western toad, and create flow or temperature conditions less favorable for rearing (i.e., flow could sweep away unattached eggs or reduce temperatures that limit developmental rates). If increased releases occur during the typical rearing interval, early larval stages that require little to no flow could be swept into unfavorable habitats downstream or be exposed to predators. Reduced temperatures associated with the operations may extend egg or larvae development periods into higher flow periods in the fall. Results of PHABSIM modeling showed that western toad spawning and rearing habitat would decrease 4.2% in the Pe Ell to Elk Creek reach and increase 4.6% from the Elk Creek to South Fork Chehalis reach under the proposed flows from MPD operations and with climate change in summer (Table 6.3). Modeling for western toad was limited to the two uppermost reaches because of lack of data from further downstream, but this should not be interpreted as a lack of presence in those reaches.

Table 6.3
Percent Change in Hydraulic Habitat (WUA) Related to Decreases in Summer Stream Flow of -16.8% in July, -26.0% in August, and -18.4% in September from Climate Change and Proposed MPD Operations Relative to Current (Baseline) Conditions

SPECIES	MAIN CHANNEL				
	PE ELL TO ELK CREEK	ELK CREEK TO SOUTH FORK	SOUTH FORK TO NEWAUKUM	NEWAUKUM TO SKOOKUMCHUCK	SKOOKUMCHUCK TO PORTER
Pacific lamprey	2.2%	8.7%	4.2%	NE	9.8%
Largemouth bass	NA	8.4%	5.1%	NE	13.7%
Smallmouth bass	NA	3.6%	3.3%	NE	6.7%
Speckled dace - rearing only	2.5%	2.1%	2.5%	NE	7.5%
Largescale sucker	5.5%	3.4%	1.8%	NE	4.4%
Mountain whitefish	-11.2%	-10.2%	-10.6%	NE	-15.2%
Western toad – rearing only	-4.2%	4.6%	NA	NA	NA

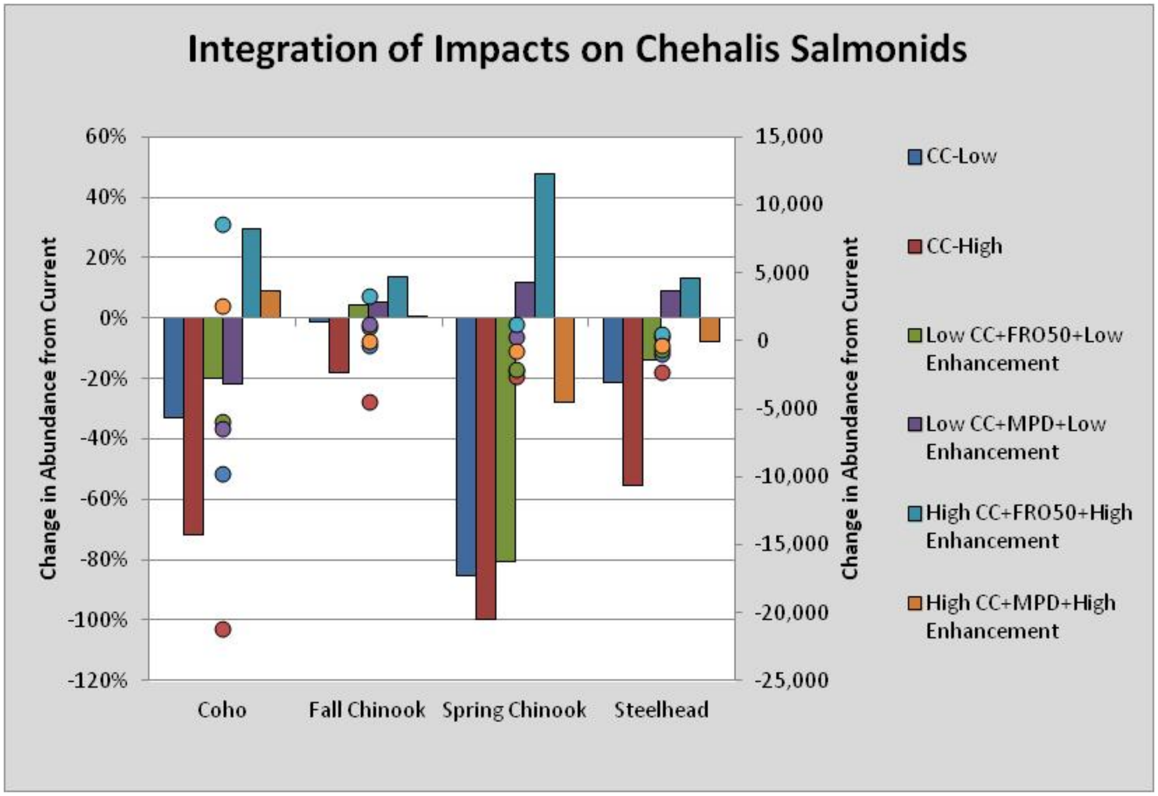
Notes:
Changes in spawning and rearing are combined unless otherwise indicated.
NA = Species not known to be present in reach at any life stage
NE = Not able to estimate

6.3 Habitat Enhancement, Water Retention, and Climate Alternatives

To assess the effects of multiple combinations of alternatives on salmon, combinations of climate change, high habitat enhancement, and water retention alternatives were modeled using EDT. The results indicated that under this combination of alternatives, habitat enhancement had to be effective and spatially extensive (i.e., the High Enhancement Alternative had to be used and had to be successful) to overcome the modeled effects of the high climate change alternative and water retention alternatives (Figure 6.11). Overall and at the basin scale, the effects of both climate alternatives was substantial. Given the apparent large role climate change may have on the Chehalis River ecosystem in the future based on these results, the need for additional studies of the potential effects of climate change in the future is identified in the companion *Data Gaps Report*.

Under this combination of alternatives, the FRO dam Alternative had greater benefits to spring-run Chinook salmon than did the MPD Alternative. This is the reverse of the results when water retention alternatives were considered by themselves without habitat enhancement or climate effects. This resulted from assumptions made about whether water temperature below a dam would be controlled by outflow from a dam or habitat enhancement actions downstream of the dam. The assumption was made that the increased summer outflow of cooler water from the MPD Alternative would control temperature, whereas habitat enhancement affected temperatures below the dam in the FRO Alternatives. The effect of this assumption was almost entirely confined to the mainstem spring-run Chinook salmon population between the South Fork and the proposed dam site. The assumed reduction in temperature from the High Enhancement actions was greater than the modeled outflow temperature from the MPD Alternative. Hence, when enhancement and flood retention alternatives were considered in combination, the FRO combined with High Enhancement resulted in a greater increase in spring-run Chinook salmon than did the MPD combined with High Enhancement, the reverse of the situation if the two dam alternatives were considered individually.

Figure 6.11
Proportional Changes in Chehalis Basin Salmonids from Current Abundance
Due to Climate Change, Habitat Enhancement, and Flood Retention Alternatives



Note: Bars represent percent change and dots represent numeric change in abundance relative to current condition.

When interpreting these model results it is important for decision makers to understand how assumptions made about salmon responses to water retention, habitat enhancement, and future climate alternatives may affect model outcomes. In the case of mainstem spring-run Chinook salmon, a key assumption was that spring-run Chinook salmon hold near their spawning habitat and are affected by changes in river flow, temperature, and habitat conditions in these reaches from the alternatives and future climate scenarios. In others words, fish behavioral response to alternative environmental conditions was not accounted for in the EDT model. Because empirical data on adult spring-run Chinook behavior and movement are unavailable, the possibility of adult spring-run Chinook movements out of the mainstem into cooler tributaries, within thermal refugia in the mainstem, and in response to cooler water being released from a MPD was not captured in the model. As noted in the companion *Data Gaps Report*, there is a need for empirical data on adult fish behavior and locations of thermal refugia in the mainstem, as well as a need for additional model studies to explore the sensitivity of the model results to this key assumption.

7 Data Gaps and Scientific Uncertainty

7.1 Introduction

One component of these analyses called for identifying data gaps that need to be filled should the Project proceed into the next phase of implementation. The reader is referred to the companion *Data Gaps Report* for a more thorough discussion of the gaps identified during assessment of water retention, climate and combinations of alternatives. The *Data Gaps Report* presents data gaps in four categories (key species and habitats, flood retention alternative modeling, climate change, and watershed restoration planning). Key components of the *Data Gaps Report* that pertain to water retention alternatives and climate change scenarios are discussed in the following sections.

7.2 Water Retention Alternatives

Data gaps associated with multiple models used to assess the potential effects of water retention alternatives on aquatic species included: 1) improvements to the HEC-RAS model and expanding its coverage into key tributaries (e.g., Newaukum River, South Fork Chehalis River, and upper Chehalis River); 2) improving the accuracy of floodplain inundation area estimates; 3) developing improved water temperature models for the mainstem and tributaries; 4) evaluating historic habitat conditions in the basin; 5) expanding the number of aquatic species modeled in EDT; 6) developing salmon life history models; 7) validating PHABSIM and HSI models for Other Fish and Non-fish Species; and 8) assessing how inundation of habitat above flood reduction structures affects rearing and spawning habitats of aquatic species.

One notable data gap identified in the *Data Gaps Report* relates to the operation of the FRO Alternative. Under current conditions, the survival of juvenile and adult fish passing the FRO Alternative and the effectiveness of fish passage facilities associated with the alternative were estimated and incorporated into model studies of the effects of the FRO Alternative on salmon. However, the lack of passage when water was impounded was considered to be small due to the frequency of impoundment and time of year and was not incorporated into the analyses. Also, the time required to manage debris was not determined until late in the Project and was not incorporated into the model studies of its effects on salmon, but was addressed in the Project by adding the cost of additional fish passage facilities to the FRO Alternative. These facilities consisted of an adult trap and collection facility below the FRO Alternative and the means to transport collected fish above the dam. In the future, the effects on aquatic resources in the basin of the time required to impound water and conduct debris management activities under the FRO Alternative with a trap and haul facility installed should be analyzed.

7.3 Climate Change

Additional data gaps for the PHABSIM and correlative climate change analysis included conducting analyses of predicted changes in flow for spring and fall, and obtaining information on the seasonal temperature profiles in side channel and off-channel habitat to understand the effect of predicted temperature increases on these habitats. Improved correlation analyses to estimate how air temperature changes affect water temperatures should be undertaken. In addition, the current stream flow projections used in climate analyses were not sufficiently calibrated. This data gap should be addressed in the future by working with the Climate Impacts Group at the University of Washington to improve the calibration of the available models used to project future stream flow changes. Further, information on the interaction between the effects of climate change and water retention alternatives on flows that create new channels and the availability of wood to initiate or support channel creation was identified as a significant data gap. Also, the potential effects from increased thermal inputs associated with a lack of riparian buffer under the FRO Alternative needs to be assessed, especially in the context of climate change. Finally, there was high uncertainty associated with the High and Low Climate Change sensitivity scenarios modeled using EDT. Additional model studies of climate variability and its potential effects on aquatic species in the Chehalis basin are needed in future phases of the Project to increase the confidence of decision makers when using the information to address management and policy questions.

Another gap identified in the *Data Gaps Report* relates to the operation of the FRO Alternative under future climate change scenarios. Two additional scenarios were analyzed late in the Project and were not incorporated into model studies of the effects of the FRO Alternative on salmon. The first scenario was an 18% increase in peak flows in the Chehalis River, and the second was a 90% increase. The amount of time fish passage at the FRO Alternative would be blocked due to water being impounded and debris management activities, as well as impaired to due to flows exceeding the 2,000 cfs (56.6 m^3/sec) design limit of the fish passage conduits in the dam were estimated to increase under both future climate scenarios (Anchor QEA 2014b). These effects were addressed in the Project by adding the cost of additional fish passage facilities to the FRO Alternative as described above. However, the potential effects of these climate scenarios on the operations of the FRO Alternative outfitted with a trap and haul facility should be incorporated into future analyses of the FRO Alternative on aquatic resources in the basin.

7.4 Scientific Uncertainty

As discussed in Section 6, many results presented throughout this report imply a certain level of precision, but typically lack an estimate of the variance associated with each result. Collectively, the results of the model studies conducted represent the likely effects and benefits to aquatic species given the data and analytical tools currently available. The models generally reflect a scientific understanding of processes on a qualitative level. However, quantitative components of the models and interactions of the components are subject to greater uncertainty. The companion *Data Gaps Report* was developed to identify many of these uncertainties. The *Data Gaps Report* acknowledges the need to reduce uncertainty, and for decision makers to have a better understanding of remaining uncertainties associated with model outputs in the future.

8 References

Adams, M.J., and R.B. Bury, 2002. The endemic headwater stream amphibians of the American northwest: associations with environmental gradients in a large forested preserve. *Global Ecology and Biogeography* 11(1):169-178.

Adams, M.J., C.A. Pearl, and R.B. Bury, 2003. Indirect facilitation of an anuran invasion by non-native fishes. *Ecology Letters* 6:343-351.

Adams, M.J., and C.A. Pearl, 2007. Problems and opportunities managing invasive bullfrogs: is there any hope? Pages 679-693 in F. Gherardi, ed. *Biological Invaders in Inland Waters: Profiles, Distribution, and Threats*. Springer, New York.

Adams, M.J., C.A. Pearl, S. Galvan, and B. McCreary, 2011. Non-native species impacts on pond occupancy by an anuran. *The Journal of Wildlife Management* 75(1):30-35.

Anchor QEA, 2012a. *Chehalis River Basin Comprehensive Salmonid Habitat Enhancement Plan*. Prepared for the Chehalis River Basin Flood Authority. Seattle, Washington.

Anchor QEA, 2012b. *Chehalis River Flood Storage Dam Fish Population Impact Study*. Prepared for Chehalis River Basin Flood Authority, Lewis County Board of County Commissioners. April 2012.

Anchor QEA, 2012c. *Appendix C: Water Quality Evaluations Chehalis Flood Authority Fish Study*. Prepared for the Chehalis River Basin Flood Authority. Seattle, Washington. April 2012.

Anchor QEA, 2014a. Draft Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species - Preliminary Dam Operations Plan Summary.

Anchor QEA, 2014b. Draft Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species – Fish Passage Delay Times at Flood Retention Only Dam.

Andrusak, G., and H. Andrusak, 2011. Identification of Habitat Use and Preferences of Speckled Dace within the Kettle River Watershed. Redfish Consulting Ltd. Prepared for Department of Fisheries and Oceans Canada, Nelson, British Columbia.

Baltz, D., P. Moyle, and N. Knight, 1982. Competitive interactions between benthic stream fishes, riffle sculpin, *Cottus gulosus*, and speckled dace, *Rhinichthys osculus*. *Canadian Journal of Fisheries and Aquatic Sciences* 39(11):1502-1511.

Bartelt, P.E., R.W. Klaver, and W.P. Porter, 2010. Modeling amphibian energetics, habitat suitability, and movements of Western toads, *Anaxyrus* (=*Bufo*) *boreas*, across present and future landscapes. *Ecological Modeling* 221:2675-2686.

Batty, A., 2010. Examination of speckled dace abundance, biology, and habitat in the Canadian range. Honors Thesis, Simon Fraser University, Vancouver, British Columbia, Canada.

Beecher, H.A., and R.F. Fernau, 1982. Fishes of oxbow lakes of Washington. *Northwest Science* 57(2):125-131.

Beecher, H.A., T.H. Johnson, and J.P. Carleton, 1993. Predicting microdistributions of steelhead parr from depth and velocity criteria: Test of an assumption of the Instream Flow Incremental Methodology. *Canadian Journal of Fisheries and Aquatic Sciences* 50 (11):2380-2387.

Beecher, H.A., J.P. Carleton, and T.H. Johnson, 1995. Utility of depth and velocity preferences for predicting steelhead parr distribution at different flows. *Transactions of the American Fisheries Society* 124:935-938.

Beecher, H.A., B.A. Caldwell, S.B. DeMond, D. Seiler, and S.N. Boessow, 2010. An empirical assessment of PHABSIM using long-term monitoring of coho salmon smolt production in Bingham Creek, Washington. *North American Journal of Fisheries Management* 30(6):1529-1543.

Beechie, T., G. Pess, P. Roni, and G. Giannico, 2008. Setting River Restoration Priorities: A Review of Approaches and a General Protocol for Identifying and Prioritizing Actions. *North American Journal of Fisheries Management* 28(3)891-905.

Benner, P.A., and R. Sedell, 1997. Upper Willamette River landscape: a historical perspective. Pages 23-47, *in* A. Laenen and D. A. Dunnette (eds.), *River quality: dynamics and restoration*. CRC Press, Boca Raton, Florida.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.D. Stalnaker, J. Taylor, and J. Henriksen, 1998. Stream habitat analysis using the Instream Flow Incremental Methodology. U.S. Geological Survey, Biological Resources Division, Information and Technical Report USGS/BRD-1998-0004.

Buffinton, J., C. Jordan, M. Merigliano, J. Peterson, And C. Stalnaker, 2014. Review Of The Trinity River Restoration Program Following Phase 1, With Emphasis On The Program's Channel Rehabilitation Strategy. Trinity River Restoration Program. Available from: http://odp.trrp.net/Data/Documents/Details.aspx?document=2172.

Burke, M., K. Jorde, and J.M. Buffington, 2009. Application of a hierarchical framework for assessing environmental impacts of dam operation: Changes in streamflow, bed mobility and recruitment of riparian trees in a western North American river. *Journal of Environmental Management* 90:S224-S236.

Burns, D.A., and J.J. McDonnell, 1998. Effects of a beaver pond on runoff processes: comparison of two headwater catchments. *Journal of Hydrology* 205(3-4):248-264.

Caldwell, B, J. Pacheco, H. Beecher, T. Hegy and R, Vadas, 2004. Chehalis River Basin WRIA 22 and 23 Fish Habitat Analysis Using the Instream Flow Incremental Methodology. Prepared by the Washington Department of Ecology and the Washington Department of Fish and Wildlife. March 2004, Open File Technical Report. 04-11-006.

CBP (Chehalis Basin Partnership), 2004. Basin Description for the Watershed Plan, Supplemental Section III. April 9, 2004. Available from: http://www.chehalisbasinpartnership.org.

CIG (Climate Impacts Group), 2010. Hydrologic Climate Change Scenarios for the Pacific Northwest Columbia River Basin and Coastal Drainages. Climate Impacts Group, University of Washington, Seattle. Available from: http://warm.atmos.washington.edu/2860/.

Crozier, L., and R. W. Zabel, 2006. Climate impacts at multiple scales: Evidence for differential population responses in juvenile Chinook salmon. *J. Anim. Ecol.* 75(5):1100-1109.

Cushman, K.A., and C.A. Pearl, 2007. A Conservation Assessment for the Oregon Spotted Frog (*Rana pretiosa*). USDA Forest Service Region 6 and USDI Bureau of Land Management, Oregon and Washington.

Dale, V. H., L. A. Joyce, S. McNulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, D. Simberloff, F. J. Swanson, B. J. Stocks, and B. M. Wotton, 2001. Climate change and forest disturbances. BioScience 51(9):723-734.

Dauble, D., 1986. Life history and ecology of the largescale sucker (*Catostomus macrocheilus*) in the Columbia River. *American Midland Naturalist* 116(2):356-367.

Dauble, D.D., R.L. Johnson, and A.P. Garcia, 1999. Fall Chinook Salmon Spawning in the Tailraces of Lower Snake River Hydroelectric Projects. *Trans. Am. Fish. Soc.* 128, 672-679.

Deguise, I., and J.S. Richardson, 2009. Movement behaviour of adult western toads in a fragmented, forest landscape. *Canadian Journal of Zoology* 87(1):1-11.

DFO (Department of Fisheries and Oceans Science), 1999. *Eulachon. Pacific Region Status Report B6-06.* Department of Fisheries and Oceans Science, British Columbia, Canada.

Ducharme, A., 2008. Importance of stream temperature to climate change impact on water quality. *Hydrol. Earth Syst. Sci.* 12:797-810.

Dykaar, B.B., and P.J. Wigington Jr., 2000. Floodplain formation and cottonwood colonization patterns on the Willamette River, Oregon, USA. *Environmental Management* 25:87-104.

Edmonds, R. L., R. C. Francis, N. J. Mantua, and D. L. Peterson, 2003. Sources of climate variability in river ecosystems. Pages 11-38 in R. C. Wissmar and P. A. Bisson (eds.). Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems. Bethesda, MD: American Fisheries Society

Edwards, E., G. Gebhart, and O. Maughan, 1983. Habitat suitability information: Smallmouth bass. U.S. Department of the Interior, Fish and Wildlife Service FWS/OBS-82/10.36.

Freeman, M., C. Pringle, C.M. Greathouse, and B.J. Freeman, 2003. Ecosystem-level consequences of migratory faunal depletion caused by dams. *Am. Fish. Soc. Symp.* 35:255-266

García-Berthou, E., 2002. Ontogenetic diet shifts and interrupted piscivory in the introduced Largemouth Bass (*Micropterus salmoides*). *Internationale Revue für Hydrobiologie* 87(4):353-363.

Gordon, E., and R.K. Meentemeyer, 2006. Effects of dam operation and land use on stream channel morphology and riparian vegetation. *Geomorphology* 82:412-429.

Gross, M.R., 1987. Evolution of diadromy in fishes. *American Fisheries Society Symposium* 1:14-25.

Gunckel, S., K. Jones, S. Jacobs, 2009. Spawning distribution and habitat use of adult Pacific and western brook lampreys in Smith River, Oregon. *American Fisheries Society Symposium* 72:173-189.

Hayes, M.P., T. Quinn, D.J. Dugger, T.L. Hicks, M.A. Melchiors, and D.E. Runde, 2006. Dispersion of coastal tailed frog (*Ascaphus truei*): An hypothesis relating occurrence of frogs in non-fish-bearing headwater basins to their seasonal movements. *Journal of Herpetology* 40(4):531-543.

Hayes, M.P., T. Quinn, K.O. Richter, J.P. Schuett-Hames, and J.T. Serra-Shean, 2008. Maintaining lentic-breeding amphibians in urbanizing landscapes: The case study of the northern red-legged frog. In *Urban Herpetology,* Mitchell, J.C., R.E. Jung Brown, and B. Bartholomew (eds.). *Herpetological Conservation* 3, Society for the Study of Amphibians and Reptiles. Salt Lake City, Utah, 445-461.

HDR, 2014a. *Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species: Combined Dam and Fish Passage Alternatives Draft Technical Memorandum.*

HDR, 2014b. *Interim Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species: Fish Passage Briefing Report.*

HDR, 2014c. *Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species*. Fish Passage Design Report. Internal Final Draft for Review. June 24, 2014. Prepared by: Mike Garello, P.E., Jonathon Mann, P.E., and Shaun Bevan EIT, HDR, Inc. Prepared for: Water Retention Technical Committee, and Chehalis Work Group.

HDR, 2014d. *Scenario of Small Projects, Draft List of Potential Project Memorandum*. January 2014.

Healey, M.C., 1991. Life history of Chinook salmon (*Oncorhynchus tshawytscha*). In *Pacific Salmon Life Histories*, C. Groot and L. Margolis (eds.). University of British Columbia Press, Vancouver, British Columbia, Canada. Published in cooperation with the Government of Canada, Department of Fisheries and Oceans, 311-394.

Henning, J.A., 2004. An Evaluation of Fish and Amphibian Use of Restored and Natural Floodplain Wetlands. Washington Department of Fish and Wildlife, Olympia, Washington. _Final Report. EPA Grant CD-97024901-1:81.

Henning, J., R. Gresswell, and L. Flemming, 2007. Use of seasonal freshwater wetlands by fishes in a temperate river floodplain. *Journal of Fish Biology* 71(2):476-492.

Holland, D. C. 1994. *The Western Pond Turtle: Habitat and History*. U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon.

Independent Scientific Advisory Board. 2007. Climate change impacts on Columbia Basin fish and wildlife: Northwest Power Planning and Conservation Council. Portland, Oregon.

Junk, W.J., P.B. Bayley, and R.E. Sparks, 1989. The flood pulse concept in river- floodplain systems. Pages 110-127 in D.P. Dodge, editor. Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquatic Science. 106.

Kapust, H.Q.W., K.R. McAllister, and M.P. Hayes, 2012. Oregon spotted frog (Rana pretiosa) response to enhancement of oviposition habitat degraded by Reed Canarygrass (Phalaris arundinacea). Herpetological Conservation and Biology 7(3):358-366.

Kiesecker, J.M., and A.R. Blaustein, 1997. Population differences in responses of red-legged frogs *(Rana aurora)* to introduced bullfrogs. *Ecology* 78:1752-1760.

Kiesecker, J.M., and A.R. Blaustein, 1998. Effects of introduced bullfrogs and smallmouth bass on microhabitat use, growth and survival of native red-legged frogs *(Rana aurora). Conservation Biology* 12:776-787.

Kiesecker, J.M., A.R. Blaustein, and C.L. Miller, 2001. Potential mechanisms underlying the displacement of native red-legged frogs by introduced bullfrogs. *Ecology* 82**:**1964–1970.

Kluber, M.R., D.H. Olson, and K.J. Puettmann, 2008. Amphibian distributions in riparian and upslope areas and their habitat associations on managed forest landscapes in the Oregon Coast Range. *Forest Ecology and Management* 256(4):529-535.

Kluber, M.R., D.H. Olson, and K.J. Puettmann, 2009. Downed wood microclimates and their potential impact on Plethodontid salamander habitat in the Oregon Coast Range. *Northwest Science* 83(1):25-34.

Kohn, M., 2014. Personal communication between Chip McConnaha, John Ferguson, and Mike Kohn. May 12, 2014.

Leider, S.A., M.W. Chilcote, and J.J. Loch, 1986. Comparative life history characteristics of hatchery and wild steelhead trout (Salmo gairdneri) of summer and winter races in the Kalama River, Washington. Canadian Journal of Fisheries and Aquatic Sciences 43(7):1398-1409.

Licht, L. E., 1971. Breeding habits and embryonic thermal requirements of the frog, *Rana aurora aurora* and *Rana pretiosa pretiosa*, in the Pacific Northwest. Ecology 52(1):116-124.

Ligon, F.K., W.E. Dietrich, and W.J. Trush, W.J., 1995. Downstream Ecological Effects of Dams. *BioScience* 45:183-192.

Mallett, C., 2012. NOAA Protected species studies of Eulachon smelt in Oregon and Washington. Progress Report, Oregon Department of Fish and Wildlife, Clackamas, Oregon.

Mantua, N.J., I. Tohver, and A.F. Hamlet, 2009. Impacts of climate change on key aspects of freshwater salmon habitat in Washington State. Chapter 6 of *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*, Climate Impacts Group, University of Washington. Seattle, Washington.

Mantua, N. J., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climate Change* 103:187-223.

Marmulla, G. (ed.), 2001. Dams, fish and fisheries - opportunities, challenges and conflict resolution. FAO Fisheries Technical Paper No. 419. FAO, Rome, Italy.

McCart, P., and N. Aspinwall, 1970. Spawning habits of the largescale sucker, Catostomus macrocheilus, at Stave Lake, British Columbia. *Journal of the Fisheries Research Board of Canada* 27(6):1154-1158.

McDowall, R. M., 1988. Diadromy in fishes. Portland: Timber Press.

Miller, J.A., 1993. Juvenile chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in natural and created estuarine habitats: foraging and daily growth. Master's Thesis, University of Washington. Seattle, Washington.

Minakawa, N., and R.I. Gara, 1999. Ecological effects of a chum salmon (*Oncorhynchus keta*) spawning run in a small stream of the Pacific Northwest. *Journal of Freshwater Ecology* 14(3):327-335.

Mobrand Biometrics, Inc., 2003. *Assessment of Salmon and Steelhead Performance in the Chehalis River Basin in Relation to Habitat Conditions and Strategic Priorities for Conservation and Recovery Actions.* Final Report. Prepared by Mobrand Biometrics, Inc., Vashon, Washington, for Chehalis Basin Fisheries Task Force and the Washington Department of Fish and Wildlife, December 2003.

Mongillo, P.E., and M. Hallock, 1999. *Washington State Status Report for the Olympic Mudminnow*. Washington Department of Fish and Wildlife, Olympia, Washington.

Moyle, P., and D. Baltz, 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for in-stream flow determinations. *Transactions of the American Fisheries Society* 114(5):695-704.

Moyle, P. B., 2002. *Inland Fishes of California*. Berkeley: University of California Press.

Naiman, R.J., C.A. Johnston, and J.C. Kelley, 1988. Alteration of North American streams by beaver. *BioScience.* 38(11):753-762.

Neave, E., 1966. Salmon of the North Pacific Ocean. III. Chum salmon in British Columbia. *International North Pacific Fisheries Commission Bulletin* 18:81-86.

Nestler, J. M., Goodwin, R. A., Cole, T., Degan, D., and Dennerline, D., 2002. "Simulating movement patterns of blueback herring in a stratified southern impoundment." Transactions of the American Fisheries Society 131, 55-69.

Normandeau Associates, 2012a. *Appendix D: PHABSIM Instream Flow Study*. Prepared by Normandeau Associates, Inc., Arcata, California, for Chehalis River Basin Flood Authority.

Normandeau Associates, 2012b. *Appendix E: Upper Chehalis River Watershed Habitat Evaluation*. Prepared by Normandeau Associates, Inc., Arcata, California, for Chehalis River Basin Flood Authority.

Northcote, T.C., 1978. Migratory strategies and production in freshwater fishes. In: *Ecology of Freshwater Fish Production*. Ed: Gerking, S. D. Blackwell Scientific Publications, Oxford, UK, 326-359.

Paragamian, V., G. Kruse, and V. Wakkinen, 2001. Spawning Habitat of Kootenai River White Sturgeon, Post-Libby Dam. *North American Journal of Fisheries Management* 21(1):22-33.

Parsley, M., and L. Beckman, 1994. White sturgeon spawning and rearing habitat in the lower Columbia River. *North American Journal of Fisheries Management* 14(4):812-827.

Parsley, M.J., L.G. Beckman, and G.T. McCabe, 1993. Spawning and Rearing Habitat Use by White Sturgeons in the Columbia River Downstream from McNary Dam. *Trans. Am. Fish. Soc.* 122:217-227.

Pearl, C.A., and M.P. Hayes, 2004. *Habitat Associations of the Oregon Spotted Frog (Rana pretiosa): A Literature Review*. Washington Department of Fish and Wildlife, Olympia, Washington.

Petts, G.E, 1979. "Complex response of river channel morphology subsequent to reservoir construction." Progress in Physical Geography 3: 329-362.

Petts, G.E., 1980. "Long-term consequences of upstream impoundment." Environmental Conservation 7 (4): 325-332.

Phinney, L.A., and P. Bucknell, 1975. *A Catalog of Washington Streams and Salmon Utilization, Volume 2: Coastal Region*. Washington Department of Fisheries, Olympia, Washington

Pickett, P.J., 1992. Historical data sources and water quality problems in the Chehalis River basin. First Interim Report for the Chehalis River TMDL Study. Washington Department of Ecology, Lacey, Washington.

Quinn, T.P., 2005. *The behavior and ecology of pacific salmon and trout*. Seattle: University of Washington Press.

Quinn, T.P., and N.P. Peterson, 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. *Canadian Journal of Fisheries and Aquatic Sciences* 53:1555–1564.

Ralph, S.C., N.P. Peterson, and C.C. Mendoza, 1994. *An Inventory of Off-channel Habitat of the Lower Chehalis River with Applications of Remote Sensing*. Natural Resources Consultants, Inc., for U.S. Fish and Wildlife Services, Lacey, Washington.

Ratner, S., R. Lande, and B.B. Roper, 1997. Population Viability Analysis of Spring Chinook Salmon in the South Umpqua River, Oregon. *Conservation Biology* 11:879-889.

Salo, E.O., 1991. Life history of chum salmon (*Oncorhynchus keta*). In *Pacific Salmon Life Histories,* C. Groot and L. Margolis (eds.), University of British Columbia Press, Vancouver, British Columbia, Canada. Published in cooperation with the Government of Canada, Department of Fisheries and Oceans, 231-310.

Sandercock, F.K., 1991. Life history of chum salmon (*Oncorhynchus keta*). In *Pacific Salmon Life Histories*, C. Groot and L. Margolis (eds.), University of British Columbia Press, Vancouver, British Columbia, Canada. Published in cooperation with the Government of Canada, Department of Fisheries and Oceans, 395-446.

Scoppettone, G.G. 1988. Growth and longevity of the Cui-ui and longevity of other catostomids and cyprinids in Western North America. *Transactions of the American Fisheries Society* 117(3):301-307.

Scruton, D.A., R.K. Booth, C.J. Pennell, F. Cubitt, R.S. McKinley, and K.D. Clarke, 2007. Conventional and EMG telemetry studies of upstream migration and tailrace attraction of adult Atlantic salmon at a hydroelectric installation on the Exploits River, Newfoundland, Canada. *Hydrobiologia* 582:67-79.

Smith, C., and M. Wenger, 2001. *Salmon and Steelhead Habitat Limiting Factors, Chehalis Basin and Nearby Drainages Water Resource Inventory Areas 22 and 23*. Final Report.

Snover, A.K., G.S. Mauger, L.C. Whitely Binder, M. Krosby, and I. Tohver, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. State of Knowledge Report prepared for the Washington State Department of Ecology, Climate Impacts Group. University of Washington. Seattle, Washington.

Sowa, S., and C. Rabeni, 1995. Regional evaluation of the relation of habitat to distribution and abundance of smallmouth bass and largemouth bass in Missouri Streams. *Transactions of the American Fisheries Society* 124(2):240-251.

Stone, J., and S. Barndt, 2005. Spatial distribution and habitat use of Pacific lamprey (*Lampetra tridentata*) ammocoetes in a western Washington stream. *Journal of Freshwater Ecology* 20(1):171-185.

Stuber, R., G. Gebhart, and O. Maughan, 1982. *Habitat Suitability Index Models: Largemouth Bass*. U.S. Department of the Interior, Fish and Wildlife Service FWS/OBS-82/10.16.

Taylor, E.B., 1990. Environmental correlates of life-history variation in juvenile Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum). *Journal of Fish Biology* 37(1):1-17.

Thompson, F. and R. DeGraaf, 2001. "Conservation approaches for woody, early successional communities in the eastern United States." The Wildlife Society Bulletin 29(2): 483-494.

Trush, W. J., S. M. McBain, and L. B. Leopold, 2000. Attributes of an alluvial river and their relation to water policy and management. Proceedings of the National Academy of Sciences 97:11858.

USACE (U.S. Army Corps of Engineers), 2013. *Chehalis Basin Ecosystem Restoration General Investigation Baseline Hydrology and Hydraulic Modeling - Draft Hydraulics Analysis Report*. Prepared by WEST. September 2013.

Vadas, R., 2014. Personal communication with M. Hayes. May 27, 2014.

Waples, R.S., D.J. Teel, J.M. Myers, and A.M. Marshall, 2004. Life-history divergence in Chinook salmon: Historic contingency and parallel evolution. *Evolution* 58(2):386-403.

Ward, J., and J. Stanford, 1979. *The ecology of regulated streams*. New York: Plenum Press.

Watershed GeoDynamics and Anchor QEA, 2014. *Geomorphology and Sediment Transport Draft Technical Memorandum*. Prepared for the Chehalis Basin Workgroup. March 2014.

WDFW, 2013. *Threatened and Endangered Wildlife in Washington: 2012 Annual Report*. Listing and Recovery Section, Wildlife Program, Washington Department of Fish and Wildlife, Olympia, Washington.

Weyerhaeuser (Weyerhaeuser Co.), 1994. *Chehalis Headwaters Watershed Analysis*. Federal Way, Washington.

WFC (Wild Fish Conservancy), 2011. *Climate Change in the Chehalis River and Grays Harbor Estuary*. Prepared for the Chehalis Basin Habitat Work Group. February 2013.

Wilkins, R., and N.P. Peterson, 2000. Factors related to amphibian occurrence and abundance in headwater streams draining second-growth Douglas-fir forests in southwestern Washington. *Forest Ecology and Manageme*nt 139(1-3):79-91.

Withler, I. L., 1966. Variability in life history characteristics of steelhead trout (*Salmo gairdneri*) along the Pacific Coast of North America. *Journal of the Fisheries Research Board of Canada* 23(3):365-393.

World Commission on Dams, 2000. *Dams and development: and new framework for decision-making*. London: Earthscan Publications.

Wydoski, R.S., and R.R. Whitney, 2003. Inland fishes of Washington. Second edition, revised and expanded. American Fisheries Society, Bethesda, MD, in association with the University of Washington Press. Seattle, Washington. 322 pp.