Chehalis Basin Strategy

Analysis of Salmonid Habitat Potential to Support the Chehalis Basin Programmatic Environmental Impact Statement

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ACRONYMS AND ABBREVIATIONS LIST

ASHA	Aquatic Species Habitat Actions
Ecology	Washington State Department of Ecology
EDT	Ecosystem Diagnosis & Treatment
FRFA	Flood Retention/Flow Augmentation
FRO	Flood Retention Only
NMFS	National Marine Fisheries Service
PEIS	Programmatic Environmental Impact Statement
PSU	Portland State University
RFP	Restorative Flood Protection
RM	River Mile
SEPA	State Environmental Policy Act
WDFW	Washington Department of Fish and Wildlife

EXECUTIVE SUMMARY

The Chehalis Basin Strategy has been developed to reduce flood damage and to improve aquatic habitat in the Chehalis Basin. A number of actions that met these objectives were evaluated in a Programmatic Environmental Impact Statement (PEIS), which was completed by the Washington State Department of Ecology (Ecology) in June 2017 (Ecology 2017).

Actions to reduce flood damage include a dam located in the upper Chehalis Basin near Pe Ell, Washington (RM108), and the Restorative Flood Protection (RFP) action element. Two dam types have been evaluated: the Flood Retention/Flow Augmentation (FRFA) facility and the Flood Retention Only (FRO) facility. The FRFA facility consists of a dam with a permanent reservoir, which would include additional capacity to retain floodwaters if a major flood is predicted. Water stored in the permanent reservoir during winter would be released as needed (typically during late spring through early fall) to augment flows and reduce water temperatures in portions of the mainstem Chehalis River. The FRO facility consists of a dam with a temporary reservoir. The dam would temporarily retain water if a major flood is predicted and would not impede Chehalis River flow under normal hydrological conditions or smaller floods (less than 7-year floods). RFP is intended to rebuild some of the lost natural flood storage capacity of the Chehalis Basin upstream of Chehalis by adding engineered large wood structures and plantings to create “roughness” (or resistance to flow) in river and stream channels and the floodplain and by reconnecting river channels to floodplain storage.

A number of measures were evaluated as part of the Aquatic Species Habitat Actions (ASHA) to protect existing functional habitat and improve and create sustainable ecosystem processes and functions that support the long-term health of native aquatic and semi-aquatic species at much higher levels of abundance than current conditions support. Habitat would be improved by restoring areas along the mainstem Chehalis River and in tributaries, and by adding native plants and vegetation. “Low” and “high” restoration scenarios were evaluated in the PEIS to bracket the potential range of results that could ensue from implementation of the Aquatic Species Restoration Plan, which is under development. The low and high scenarios varied in regard to spatial extent and effectiveness of riparian forest restoration.

The PEIS relied on the Ecosystem Diagnosis & Treatment (EDT) model to evaluate the biological significance of environmental changes with regard to the potential of the Basin to support spring- and fall-run Chinook, coho, and chum salmon and steelhead (“modeled species”) at basin and sub-basin scales as a result of flood damage reduction and habitat restoration actions. The actions were evaluated under current climate conditions and under projected future climate conditions in the Chehalis Basin.

Methods

The EDT model evaluated the actions in regard to the change in the potential of habitat within the Chehalis Basin to support the modeled species. The model was parameterized at a reach-scale using empirical, model-derived, and expert-based information that was evaluated against life history patterns and habitat needs of the modeled species. Potential performance of the species under the modeled condition was computed in regard to the change in adult returns (abundance) relative to the current habitat condition. The EDT model relied on a suite of physical models to provide projections of flow, temperature, and channel width along with empirical data derived from Washington Department of Fish and Wildlife habitat surveys. The physical models allowed projections of conditions under alternative operational scenarios and under future climate predictions.

Principle Findings

1. At the basin-scale under current climate conditions, the FRO and FRFA facility options resulted in a small (less than 5%) reduction in habitat potential for the modeled species. The negative impacts were least for chum salmon and greatest for spring-run Chinook salmon.
2. At the sub-basin scale, the FRO and FRFA facility options resulted in much greater reductions in habitat potential; reductions on habitat above Crim Creek (the approximate site of the proposed dam) ranged from nearly 100% (fall and spring-run Chinook salmon, FRFA) to 29% (spring-run Chinook salmon, FRO).
3. The RFP increased habitat potential several-fold compared to current conditions for spring-run Chinook salmon and coho salmon and provided lesser benefits to fall-run Chinook salmon, chum salmon, and steelhead.
4. ASHA greatly enhanced the habitat potential for spring-run Chinook salmon and coho salmon and generally throughout the upper Basin areas where large expanses of managed forest currently exist.
5. The effects of the FRFA and FRO facility options depended on the condition of habitat above the proposed dam. When habitat was restored as a result of maturation of the riparian forest, the impact of the facilities increased significantly compared to the projected impact under current habitat conditions that have been degraded by logging.
6. Future climate, as modeled in this analysis, greatly reduced habitat potential for all modeled species throughout the Chehalis Basin independent of the dam facility options or Aquatic Species Restoration Plan.
7. Under future climate conditions, habitat for most populations of spring-run Chinook salmon was eliminated suggesting this species they may not be viable under future climate conditions without substantial habitat restoration.
8. As modeled in this analysis, the negative effect of future climate conditions depended on the length of a species' exposure to conditions in the Chehalis watershed. Chum salmon and fall-run Chinook salmon spend the least amount of time in the watershed and negative effects were less under future climate conditions compared to other species. Spring-run Chinook salmon, coho

salmon, and steelhead spend considerably longer in the watershed and displayed greater negative effects of future climate conditions.

9. Climate change appreciably reduced the expected benefits from ASHA and the RFP, although overall change remained positive compared to current habitat conditions.
10. Substantial improvement of the condition of the modeled species relative to their current condition in the face of climate change only occurred under the Low60 and High60 scenarios. The analysis showed that, in the face of projected future climate, restoration needed to be pervasive across the watershed and highly effective in restoring habitat conditions to achieve fishery management objectives.

1 PURPOSE AND SCOPE

The Chehalis Basin in southwest Washington State has experienced major flooding and substantial degradation of aquatic species habitat. Since 1971, there have been 14 federally declared disasters in the Chehalis Basin from flooding. Peak flood levels have been rising in the Chehalis Basin over the last 30 years and climate scientists predict a continued increase in the years ahead (Mauger et al. 2016). Although there have been relatively robust runs of salmon and steelhead every year for the last 30 years, abundance is still much reduced compared to historical conditions and poor returns of one or more species have significantly limited tribal and non-tribal harvest.

The Governor and Washington State Legislature have made it a priority to develop a comprehensive strategy that integrates flood damage reduction and aquatic species habitat restoration in the Chehalis Basin and have invested in identifying potential solutions. The Chehalis Basin Strategy has been developed to integrate actions to maximize the benefits of flood damage reduction and aquatic species habitat restoration over both the short and long term, while avoiding and minimizing adverse environmental, social, cultural, agricultural, and economic impacts.

Washington State Department of Ecology (Ecology) prepared a State Environmental Policy Act (SEPA) Programmatic Environmental Impact Statement (PEIS) at the request of the Governor's Chehalis Basin Work Group (Ecology 2017). The Work Group has been tasked by the Governor with developing recommendations for an integrated strategy that includes measures to reduce flood damage and restore aquatic species habitat in the Chehalis Basin. The PEIS evaluates a suite of actions to address these two challenges.

This report summarizes the results of modeling conducted to analyze the adverse impacts and benefits on anadromous salmonid fish resulting from the flood damage reduction and aquatic habitat restoration actions. The actions were evaluated under current climate conditions and those projected to occur in the Chehalis Basin in the future. Actions were compared based on the change in the potential of habitat to support coho salmon (*Oncorhynchus kisutch*), fall-run and spring-run Chinook salmon (*O. tshawytscha*), chum salmon (*O. keta*) and steelhead trout (*O. mykiss*) in the Chehalis River. The effect of these actions on the five anadromous salmonids has been evaluated using the Ecosystem Diagnosis & Treatment (EDT) model (Blair et al. 2009). EDT is a salmonid life-cycle habitat model that assesses the potential of habitat to support species and populations using the metrics of the National Marine Fisheries Service (NMFS) Viable Salmonid Population concept (McElhany et al. 2000). Documentation of the Chehalis EDT model is provided in Appendix A.

The analysis indicated that under current climate and habitat conditions, the effect of the flood damage reduction actions at the scale of the Chehalis River Basin ranged from slightly negative (Flood Retention/Flow Augmentation [FRFA] and Flood Retention Only [FRO] facilities) to strongly positive

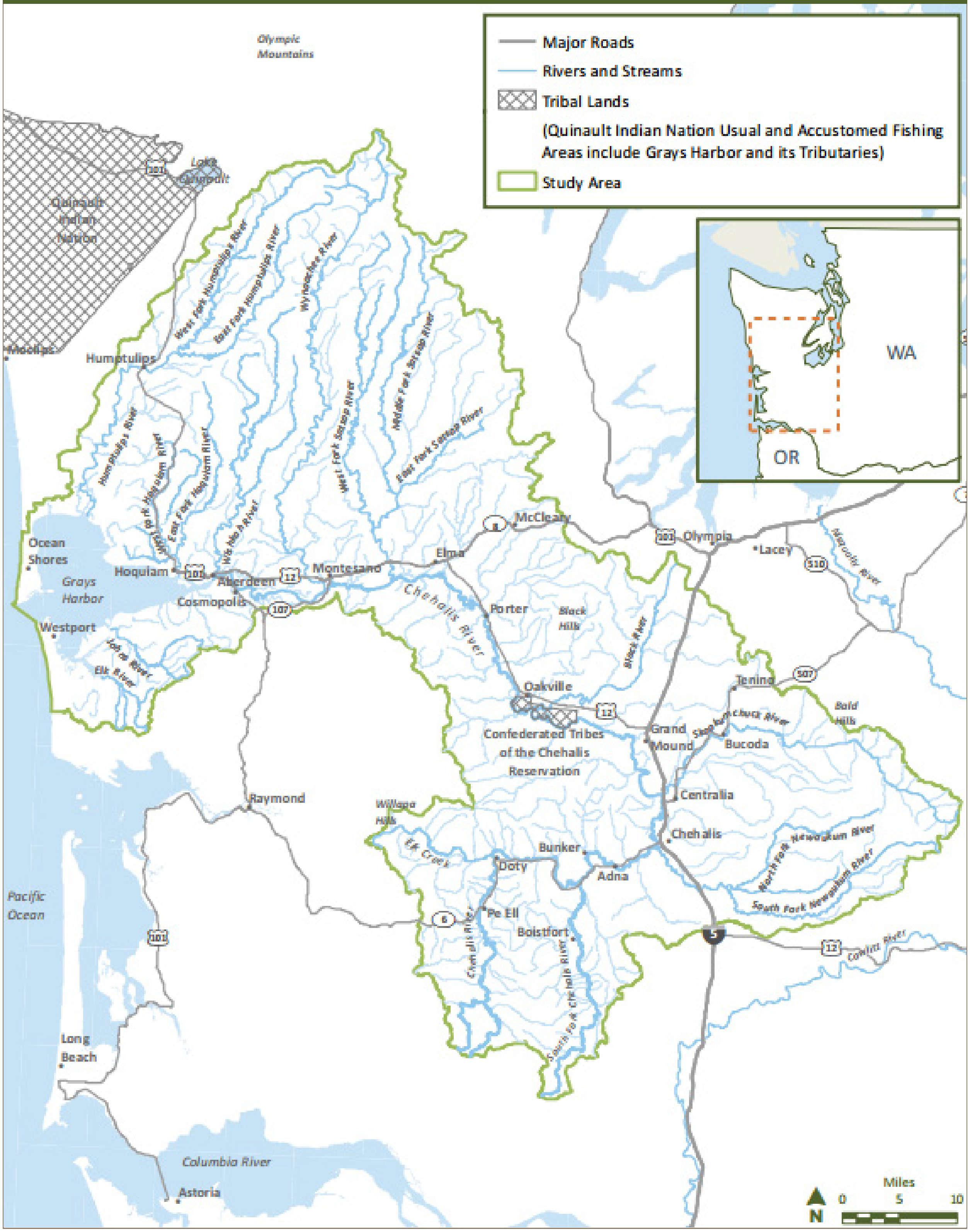
(Restorative Flood Protection [RFP]). However, the negative impact of the facilities was much greater on individual populations and especially on fish production above the site of the proposed dams. The Habitat restoration was effective in increasing habitat potential for all five modeled species across the Chehalis Basin. The analysis has shown that there are important interactions between the flood damage reduction actions, habitat restoration, and climate change. The projected effects of the dam facilities were found to be dependent on the condition of habitat affected by the dam and reservoir. Restoration of habitat conditions above the dam site appreciably increased the negative effects of the dams compared to their effect under current habitat conditions. Projected future climate had a very strong negative effect on habitat for the modeled species. Habitat restoration actions compensated for the negative effects of climate change and the flood damage reduction actions, but needed to be large scale and highly effective to overcome the effects of increased water temperature and other habitat changes associated with climate change.

2 DESCRIPTION OF THE STUDY AREA

The Chehalis Basin is located in southwestern Washington State. It is the second largest river basin within the state, extending over eight counties, including large portions of Grays Harbor, Lewis, and Thurston counties, and small parts of Pacific, Cowlitz, Wahkiakum, Mason, and Jefferson counties (Figure 1). The Chehalis River flows approximately 125 miles north-northwesterly to Grays Harbor and the Pacific Ocean, and drains an area of approximately 2,700 square miles. Many species of fish are found in the Chehalis Basin, including salmonids such as steelhead and Chinook, coho, and chum salmon (*Oncorhynchus spp*.). Extensive and varied habitats within and adjacent to rivers and streams in the Chehalis Basin also support the most diverse amphibian population in Washington, Olympic Mudminnow (*Novumbra hubbsi*), and numerous other native fish and wildlife species.

Land use in the Basin falls into two general categories: areas within managed forest and areas outside of managed forest. Areas within managed forest are dominated by large commercial/industrial forestry as well as smaller-scale commercial forest operations. These areas are largely in the upper portions of most Chehalis sub-basins characterized by higher elevations, steeper topography, thin soils, and exposed bed rock. Streams within managed forest are typically small with a relatively high gradient, and are often confined by valley walls. Areas outside of managed forest are usually at lower elevations in valley bottom areas characterized by agricultural and urban development. These areas have relatively flat topography and deep soils. Outside managed forest the river is often alluviating, with a low gradient and low levels of natural confinement.

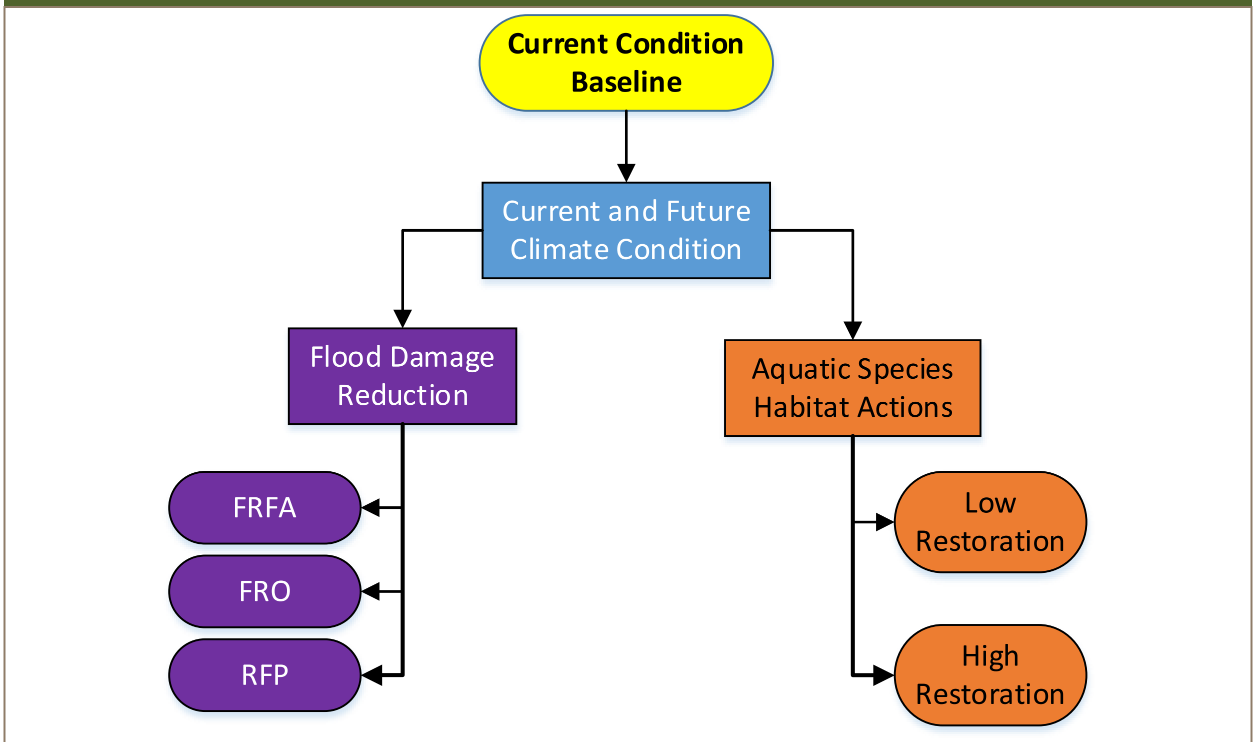
Figure 1
Chehalis Basin Study Area



3 ACTIONS EVALUATED FOR THE PEIS

The PEIS covered two categories of actions that were evaluated using the Chehalis EDT model (Figure 2). The first category, Flood Damage Reduction Actions, evaluated measures to reduce damage from periodic flooding. This included alternatives using a dam (with associated reservoir) to store and release flood waters (FRFA and FRO facility options) and an alternative designed to enhance connectivity between the river and floodplain to store and moderate floods (RFP). Detailed descriptions of the flood damage reduction actions are included in the PEIS (Ecology 2017). The second category, Aquatic Species Habitat Actions (ASHA), focused on the potential of habitat restoration throughout the Chehalis Basin to restore anadromous salmonids and other fish and non-fish species. These actions evaluated broad-scale restoration of habitat conditions across the Chehalis Basin. Restoration was bracketed by spatial extent and effectiveness into a Low and High scenario. Combinations of flood damage reduction actions, ASHA restoration, and future climate were evaluated to assess the integrative effects of the measures.

Figure 2
Structure of the Chehalis Salmonid Habitat Analysis



Notes:
FRFA = Flood Retention/Flow Augmentation
FRO = Flood Retention Only
RFP = Restorative Flood Protection

3.1 Flood Damage Reduction Actions

Actions for reducing flood damage in the Chehalis Basin included two flood retention facilities and a third action to increase river-floodplain connectivity and provide floodplain storage of flood waters, as described below:

1. An FRFA action that consists of a dam with a permanent reservoir, which would include additional capacity to retain floodwaters in the event that a major flood is predicted. Water stored in the permanent reservoir during winter would be released as needed (typically during late spring through early fall) to augment flows and reduce water temperatures in portions of the mainstem Chehalis River.
2. An FRO action that consists of a dam with a temporary reservoir. The dam would retain water in the event that a major flood is predicted. The stored water would be gradually released after the flood event and the project would not otherwise impede Chehalis River flow under normal hydrological conditions or smaller floods (less than 7-year floods).
3. RFP is intended to rebuild some of the lost natural flood storage capacity of the Chehalis Basin upstream of Chehalis by adding engineered large wood structures and plantings to create “roughness” (or resistance to flow) in river and stream channels and the floodplain, and by reconnecting river channels to floodplain storage.

3.1.1 Flood Retention Facilities

Both the FRFA and FRO facility options would entail construction of a dam on the upper Chehalis River just below Crim Creek at River Mile (RM) 108. The facility options would affect habitat above and below RM 108 with impacts on anadromous salmonids. Physical impacts of the flood retention facilities are described more fully in Chapter 4 of the PEIS (Ecology 2017).

3.1.1.1 Flood Retention/Flow Augmentation Facility

The FRFA facility would be a conventional flood storage facility with a 130,000 acre-feet permanent reservoir (Ecology 2017). The reservoir would be lowered during summer and early fall to provide winter flood storage and to augment summer flow below the dam. Adult and juvenile fish passage facilities would be provided at the facility. All mainstem and tributary reaches encompassed by the reservoir footprint would be converted from existing riverine habitats to reservoir habitats. Reaches above the reservoir would remain in their current state.

3.1.1.1.1 FRFA Assumptions

Fish passage. Passage of adult salmonids around the facility would be provided through trap and haul and/or fish ladder to locations above the facility while a juvenile collection system would assist downstream movement of juvenile fish. Capture and movement of adult and juvenile fish would result in mortality; fish passage survival rates for the FRFA facility used in this analysis were recommended by the Fish Passage Subcommittee of the Dam Design Technical Committee[1] (Table 1). No additional mortality of adults was assumed from the point of release to the streams above the reservoir. Impacts of the dams on survival of other species is discussed in the PEIS (Ecology 2017).

Table 1
Fish Passage Survival Rates Assumed for the FRFA Facility

SPRING-RUN CHINOOK SALMON	
Adult Upstream	85%
Juvenile Upstream	6%
Juvenile Downstream	64%
FALL-RUN CHINOOK SALMON	
Adult Upstream	85%
Juvenile Upstream	6%
Juvenile Downstream	64%
COHO SALMON	
Adult Upstream	85%
Juvenile Upstream	6%
Juvenile Downstream	64%
WINTER STEELHEAD	
Adult Upstream	85%
Juvenile Upstream	6%
Juvenile Downstream	64%

Tributaries above the reservoir. All habitat conditions in streams above the reservoir were unchanged from the current habitat conditions. The lengths of the streams were reduced by the average inundation extent of the FRFA reservoir.

Reservoir. The FRFA reservoir would thermally stratify, resulting in a warm surface layer (epilimnion) over a cooler deep layer (hypolimnion). Temperature in the reservoir was modeled using a CE-QUAL-W2 model by Anchor QEA (Figure 3). Juvenile salmonids in the reservoir would be affected by epilimnion temperatures, so those temperatures were used to characterize the reservoir conditions for the model. Conditions downstream of the facility would be affected by summer releases of cooler water from the hypolimnion.

Two habitat types were developed to describe conditions in the FRFA reservoir. Littoral habitat—nearshore habitat shallower than 3 meters (10 feet)—made up 5.8% of reservoir area (93 acres). Limnetic habitat—areas deeper than 3 meters (10 feet)—was 94.2% of reservoir area (1,507 acres).

The effect of the FRFA reservoir on modeled salmonids originating from the streams above the reservoir depended upon the affinity of salmonids at different life stages for littoral or limnetic habitat and the

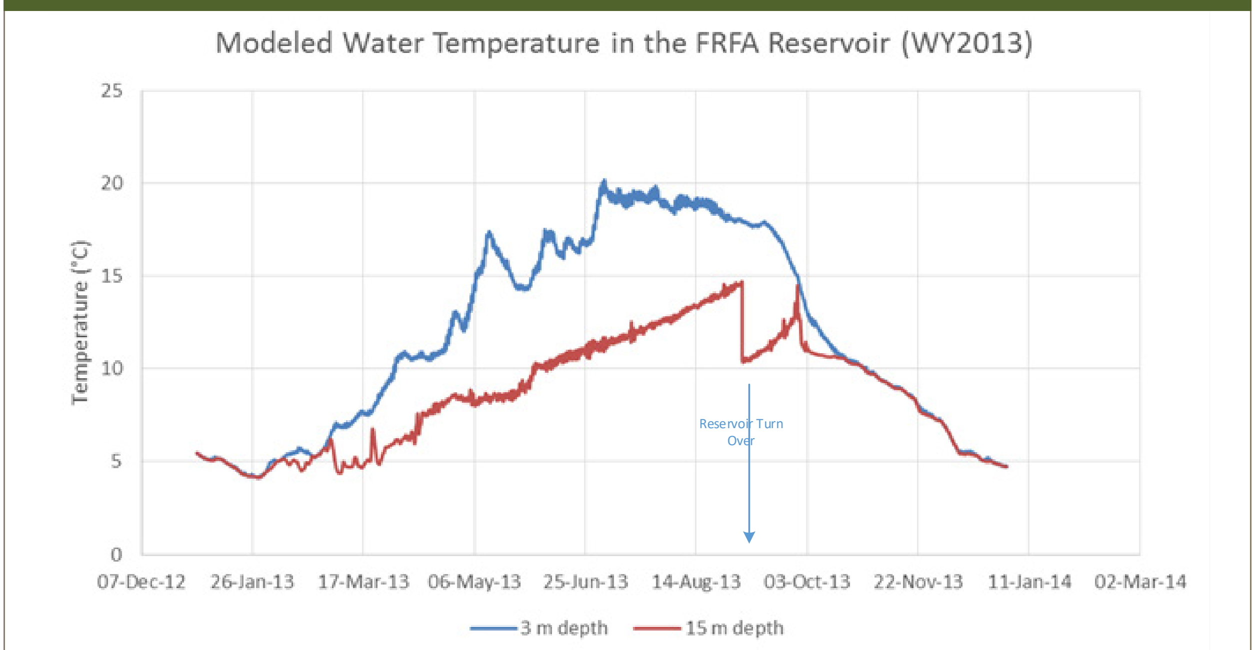
[1] The Dam Design Technical Committee included representatives from the Washington Department of Fish and Wildlife (WDFW), U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service, Washington State Department of Ecology, Quinault Indian Nation and the State of Washington Consultant Study Team.

length of exposure to the reservoir based on behavior and life history. For the FRFA reservoir, juvenile salmonids of all species were assumed to have a greater affinity for shallow littoral habitat than for deeper limnetic habitat. As they mature, fish generally move off-shore into limnetic habitat and eventually emigrate toward the ocean (Tabor et al. 2011; Monzyk et al. 2013).

Based on assumed behavior and life history, juvenile coho salmon had appreciably greater exposure to conditions in the FRFA reservoir compared to the other species. Coho salmon were assumed to have a typical 1-year freshwater life history before smoltification in their second spring and downstream emigration (Smith and Wenger 2001). A portion of them were assumed to disperse downstream soon after emergence and encounter the reservoir as fry in their first spring. Fry were assumed to gravitate to littoral areas, rear in the reservoir for some months, and then move off-shore prior to emigration the following spring.

Chinook salmon were assumed to have an ocean-type life history (Smith and Wenger 2001), emigrating to the estuary and ocean in their first spring and having limited exposure to conditions in the reservoir and largely during juvenile and adult migration periods. Steelhead were assumed to remain in natal streams above the reservoir for the length of their freshwater residency (up to 2 years). Because steelhead were assumed not to move downstream into the reservoir until emigration, their exposure to reservoir conditions was assumed to be brief.

Figure 3
Water Temperature in the FRFA Reservoir at Two Depths Modeled Using the CE-QUAL-W2 Model



Source: Anchor QEA

3.1.1.2 Flood Retention Only Facility

The FRO facility would temporarily retain water in the event that a major flood is predicted and would not impede Chehalis River flow under normal hydrological conditions or smaller floods (less than 7-year floods with a 15% probability in any year; Ecology 2017). After a storm event, the reservoir would be slowly lowered to the un-impounded state. The area above the facility that would be impounded during storm events would be selectively cleared of large trees, resulting in a decrease in riparian function and an increase in downstream water temperature as a result of reduced riparian shading. When the facility is not impounding water, water, sediment, and some woody debris would move through the facility and be transported downstream. However, because of the size of the conduits, selective clearing of riparian forest, and other issues, the FRO is expected to reduce the delivery of large wood below the dam.

The analysis evaluated the habitat conditions that would be expected to develop in the river and streams above the FRO facility as a result of the periodic impoundment and the selective clearing of the riparian forest. It did not evaluate habitat conditions that would appear during the episodic inundations (once every 7 years) or the possible effect that periodic inundation might have on long-term viability of salmonids above the FRO facility.

3.1.1.2.1 FRO Facility Assumptions

Fish passage. Outside of flood-storage events, adult and juvenile fish could pass through the FRO facility via the conduits that would pass river flow. Survival conditions of all life stages and species past the FRO facility were assumed to be appreciably higher than for the FRFA facility. Fish passage survival assumptions used in this analysis for the FRO facility through the conduits were those recommended by the Fish Passage Subcommittee of the Dam Design Technical Committee (Table 2).

Table 2
Fish Passage Survival Rates Used for the FRO Facility

MIGRATION PATTERN	FRO
SPRING-RUN CHINOOK SALMON	
Adult Upstream	94%
Juvenile Upstream	59%
Juvenile Downstream	85%
FALL-RUN CHINOOK SALMON	
Adult Upstream	94%
Juvenile Upstream	59%
Juvenile Downstream	85%
COHO SALMON	
Adult Upstream	94%
Juvenile Upstream	59%
Juvenile Downstream	85%
WINTER STEELHEAD	
Adult Upstream	96%
Juvenile Upstream	79%
Juvenile Downstream	95%

Tributaries above the reservoir. All habitat conditions in streams above the footprint of the temporary flood storage reservoir were unchanged from current habitat conditions.

Reservoir. Within the perimeter of the temporary storage reservoir, habitat in tributaries and the Chehalis River was degraded relative to its current condition to reflect removal of riparian vegetation and increased temperature and sedimentation that would occur during inundation periods (Ecology 2017). The temporary reservoir that would form during occasional storm events was not modeled; instead, the model showed the effect of the inundation on the "normal" conditions of the riverine environment above the FRO facility.

3.1.1.3 Conditions Downstream of the Flood Retention Facilities

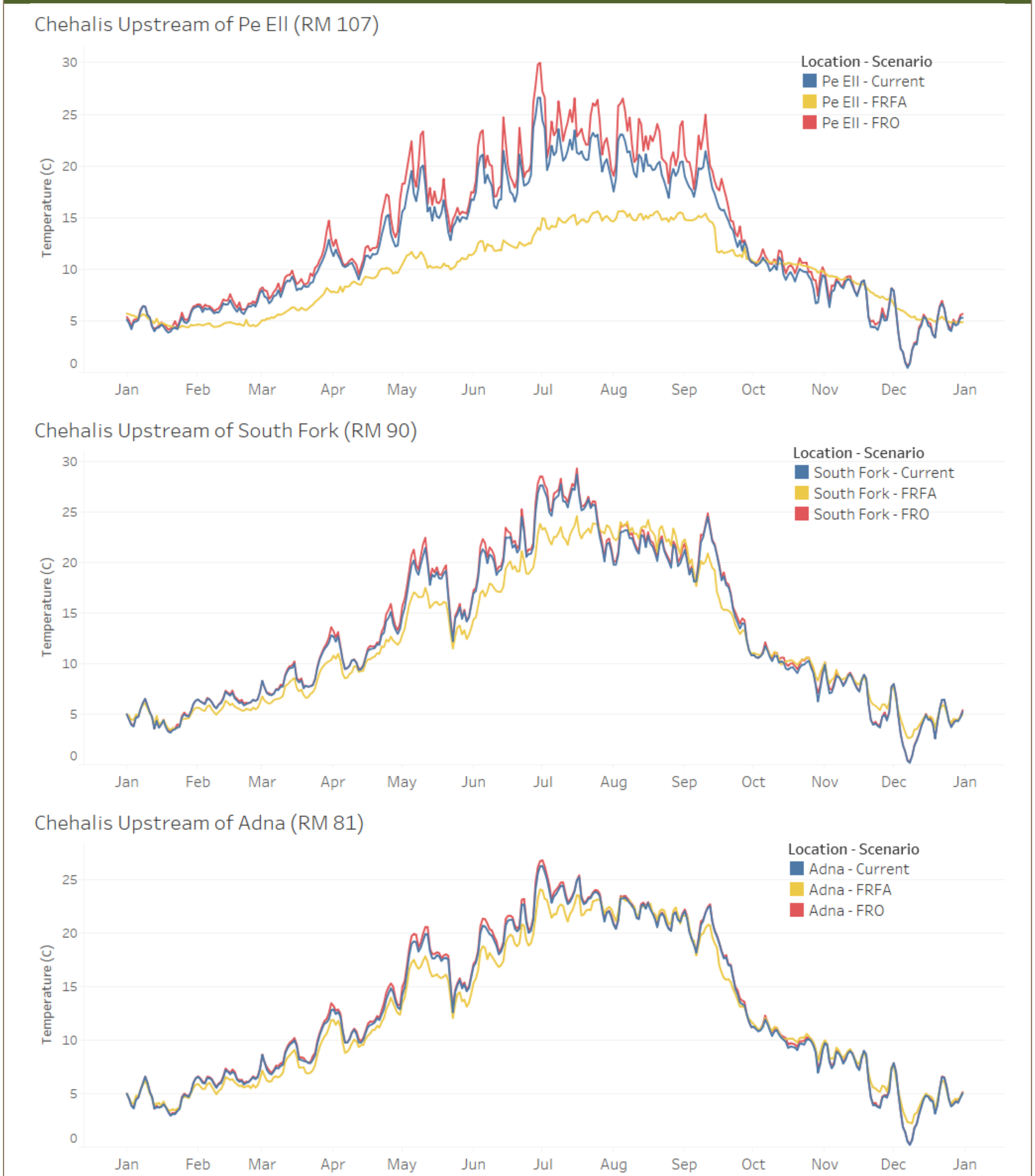
3.1.1.3.1 Water Temperature below the Facilities

Operation of the FRFA and FRO facilities would alter water temperature below the dam at RM 108 (Figure 4). Daily maximum water temperature below the proposed facilities was modeled by Portland State University (PSU) using a CE-QUAL-W2 model (Van Glubt et al. 2016). The PSU model provided detailed predictions of water temperature under the various scenarios, including future climate.

The FRFA facility would create a thermally stratified reservoir; water in the deeper hypolimnion area would be considerably colder than water in the upper epilimnion area prior to turn over of the reservoir in the fall (Figure 3). Release of hypolimnetic water during spring and summer would reduce water temperature in the river below the facility relative to the current modeled temperature (Figure 4). After turn-over of the reservoir in the fall, water temperature in the reservoir would be more uniform, resulting in slightly warmer fall temperatures compared to the current temperature below the facility (Figure 4). During the summer, the water below the FRFA facility would warm as it moved downstream, but would remain cooler than current temperature as far as Adna at RM 81 (Figure 4).

The FRO facility would not impound water except during periodic major winter storm events. Otherwise, the river would flow though the facility unimpeded. However, the PSU modeling indicates that the FRO facility would slightly increase temperature in the river below the facility due to clearing of the riparian forest above the facility and increased solar heating (Figure 4). The modeled FRO temperature quickly converged on the modeled current water temperature and was indistinguishable from the current condition downstream of the South Fork Chehalis River (Figure 4).

Figure 4
Modeled Water Temperature in the Chehalis River at Three Points Along the River Starting at the Proposed Dam Site Above Pe Ell for the FRFA and FRO Facilities Under Current Conditions



Source: PSU CE-QUAL-W2 modeled data

3.1.1.3.2 River Below the FRFA Facility

The FRFA facility would significantly alter stream flow in the river below the facility (Ecology 2017). In general, outflows from the FRFA facility would be increased during summer relative to unimpeded conditions and early fall to provide winter flood storage. Based on the HEC-RAS modeling (Anchor QEA) the increased summer flow would also increase channel width below the FRFA facility. Winter peak flow would be reduced. Downstream movement of large wood and sediment would be reduced as a result of the FRFA facility.

3.1.1.3.3 River Below the FRO Facility

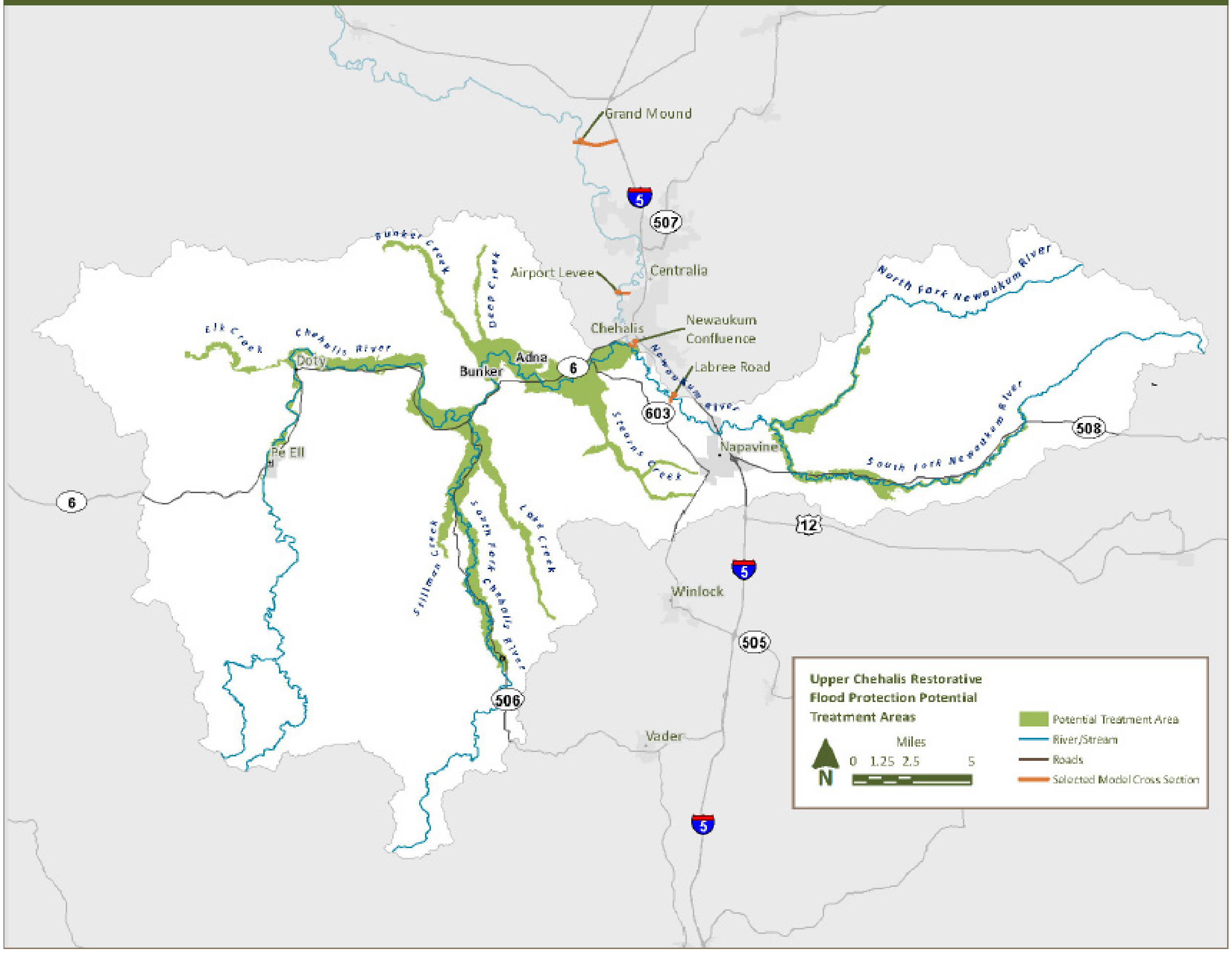
Except when storing episodic high floods, the FRO facility would not alter stream flow below the facility (Ecology 2017). However, the dam was assumed to impede downstream movement of wood and sediment. These impacts on conditions in the river downstream of the FRO facility were based on a hypothesis developed by an expert panel (Appendix A).

3.1.2 Restorative Flood Protection Action

Development of the RFP action occurred during the PEIS scoping period. This action would restore normative floodplain connection in the area upstream of Chehalis (Figure 5) and allow water from high-precipitation events to spread onto the floodplain and buffer downstream flood pulses to reduce flood damage (Abbe et al. 2016). This action would involve restoration of riparian and floodplain forest and land use changes to approximately 21,000 acres of Chehalis Basin floodplain. It would greatly increase the amount of instream large wood, which would capture sediment to increase river and floodplain roughness and to reconnect the river and floodplain and allow flood waters to move laterally onto the floodplain.

In consultation with the RFP design team (Abbe 2017; Lestelle 2017), modeling of the RFP action in the Chehalis EDT model assumed that the action would result in restoration of historic conditions within the RFP treatment area (Figure 5). Outside the RFP treatment area, all conditions were set to those in the current scenario. A key feature of the RFP is the restoration of floodplain and channel complexity. The extent of these habitat features in the RFP were estimated by Natural Systems Design based on LiDAR and GIS data.

Figure 5
Potential Treatment Areas in the Restorative Floodplain Action



Source: Figure 1-1 from Abbe et al. 2016

3.2 Aquatic Species Restoration Plan

The ASHA evaluated strategic approaches to habitat restoration for the PEIS. For these purposes, the restoration treatment applied to all selected reaches was restoration of riparian forests and the associated changes to aquatic conditions. All restoration was assumed to be modeled at full maturation of riparian forests.

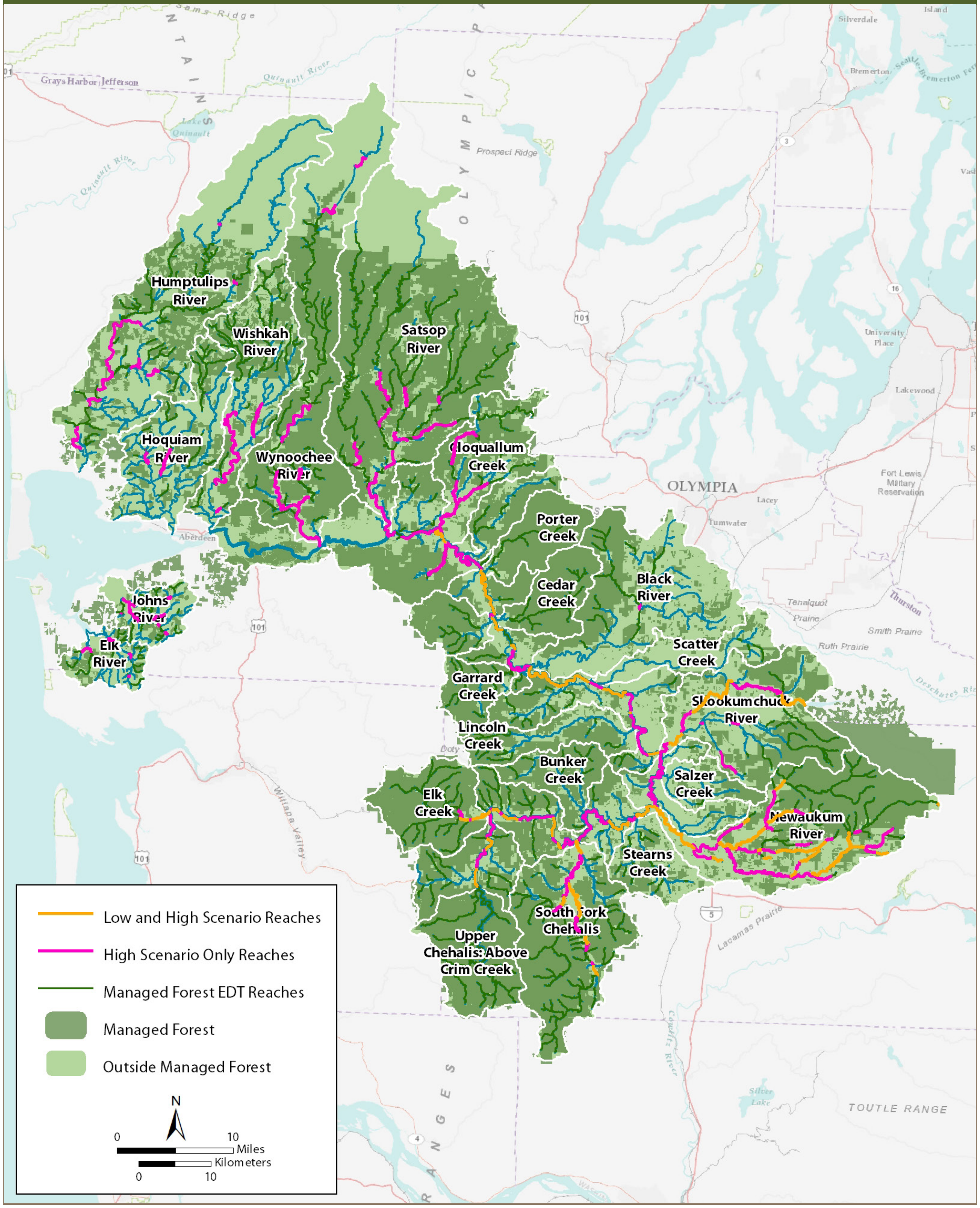
Four alternatives for application of the riparian restoration treatment were developed for the ASHA based on land use and biological priorities. The alternatives are designated as Low or High based on the spatial extent of restoration and further distinguished based on effectiveness of riparian restoration to change conditions in stream reaches (Table 3). Low or High restoration refers to the selection of reaches based on land use. To select reaches for restoration, the Basin was divided into two regions reflecting areas of commercial managed forest (mainly upper Basin and upper tributary reaches) and areas outside managed forest (mainly lower stream reaches and valley bottom with agriculture and urban development) (Figure 6). Within the managed forest areas, all stream reaches were selected for restoration treatment in both the High and Low restoration alternatives. This was because managed forest areas are subject to the Washington Forest Practices Act that mandates preservation of riparian buffers in areas subject to commercial logging. The modeling assumed that riparian areas within managed forest area were mature (likely 50-100 years in the future) as a result of passive restoration of the forest and conditions in the stream reaches were improved consistent with conceptual models developed by an expert panel (Appendix A). Areas outside managed forest are not subject to the Washington Forest Practices Act. In areas outside managed forests, the selection of reaches for restoration reflected restoration priorities for different modeled species. In the Low restoration scenario, reaches were selected to capture 50% of the spring-run Chinook salmon spawning area outside managed forest. In the High Restoration scenario, Diagnostic Units and portions of Diagnostic Units outside managed forest were selected based on prioritized restoration potential for all five modeled species up to the cumulative 90% of total restoration potential.

The effectiveness of riparian restoration to change aquatic habitat attributes in EDT was modeled at two levels (Table 3). An expert panel mapped restoration of riparian forest onto EDT attributes and hypothesized the maximum effectiveness of riparian conditions to control these attributes (Appendix A, Box 4). Intensity scalars of 20% and 60% were then applied to the hypothesized maximum effectiveness. The intensity scalars reduced the maximum effectiveness of riparian restoration, providing a more conservative estimate of actual riparian restoration. This estimate more accurately reflects 1) scientific uncertainty in how riparian forests affect instream conditions and 2) uncertainty in implementation of restoration across the Chehalis Basin.

Table 3
ASHA Restoration Scenarios

RESTORATION SCENARIO	OUTSIDE MANAGED FOREST		INSIDE MANAGED FOREST	
	SELECTION	EFFECTIVENESS	SELECTION	EFFECTIVENESS
Low20	50% of spring-run Chinook salmon spawning reaches	20%	All Reaches	20%
Low60	Same as Low20	60%	All Reaches	60%
High20	Prioritized Diagnostic Units to yield 90% restoration potential; includes spawning reaches for spring- and fall-run Chinook salmon, coho salmon, chum salmon, and steelhead with the highest restoration potential	20%	All Reaches	20%
High60	Same as High60	60%	All Reaches	60%

Figure 6
Low and High Scenarios in the Chehalis Basin and Extent of Managed Forest



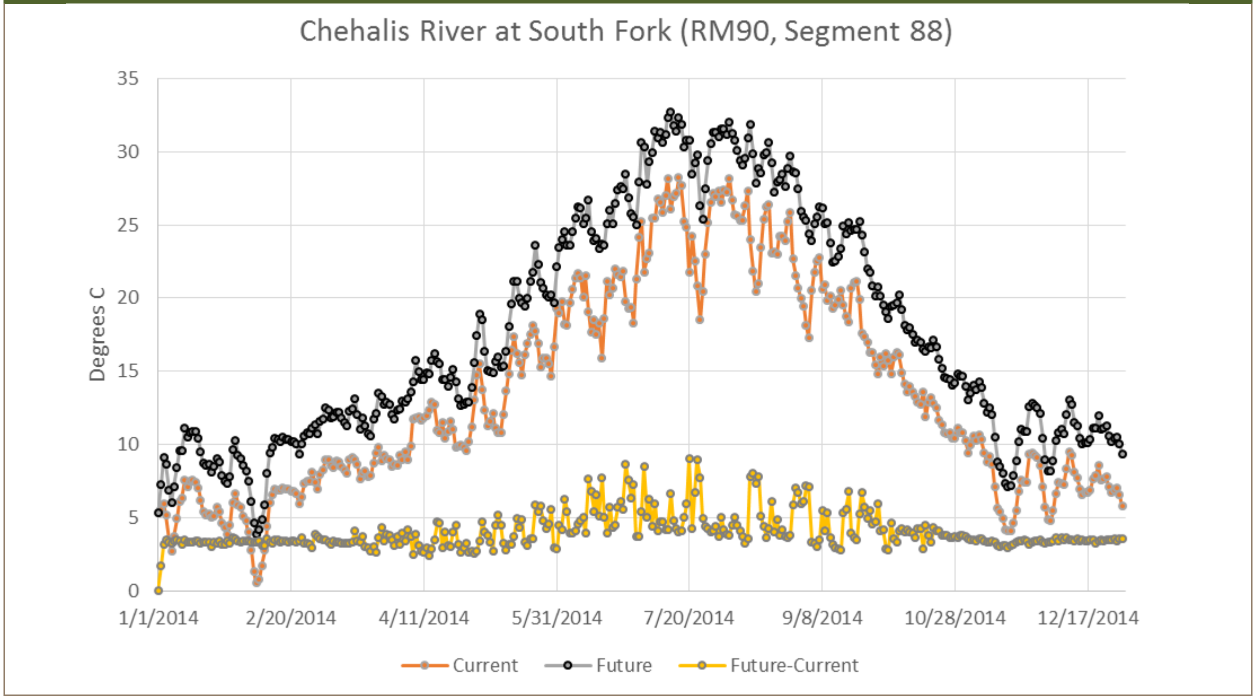
3.3 Climate Change

Climate globally and in the Pacific Northwest is projected to change significantly in the future (IPCC 2013). By 2050, climate in Washington State is expected to be 4.1 to 5.2 degrees C warmer than at present during summer (Mote et al. 2013). Relatively small changes in annual precipitation are expected in winter, spring, and fall; however, summer precipitation is expected to decrease along with streamflow. Winter storm events are expected to be larger and winter peak flows are expected to increase with the 2-year flood being 16% higher and the 100-year flood 66% higher than under current climate (Mauger et al. 2016). River flow in the Chehalis River is almost entirely rain-driven and predicted decreases in snow pack for other areas of Washington will not affect the Chehalis River. However, increased frequency and intensity of winter storm events may increase winter rates of sediment transport, erosion, and landslides (Mauger et al. 2016).

Water temperature in the Chehalis River in the future was modeled by PSU using the CE-QUAL-W2 model (Van Glubt et al. 2016). By 2050, water temperature in the mainstem Chehalis River in August was projected to increase by 5 to 10 degrees C compared to current conditions, and warmer water temperature could persist into the fall (Figure 7). Results of the PSU modeling were incorporated into the Chehalis EDT model to evaluate the effects of future climate on the modeled species.

An important caveat on this analysis is that future climate change was only evaluated with respect to conditions in fresh water in rivers and streams within the Chehalis Basin upstream of Grays Harbor and did not account for changes in future conditions in the estuary or marine areas; current conditions within Grays Harbor and the ocean were assumed throughout the analysis. Future climate is expected to modify marine conditions and will likely have adverse impacts on salmonid survival (Hare and Francis 1995; Abdul-Azia et al. 2011; Malick et al. 2015). To the extent that changes to conditions in Grays Harbor and the ocean as a result of future climate adversely affect Chehalis Basin salmonids, the results presented here are likely minimum estimates of the total climate change impact.

Figure 7
Temperature Change in the Mainstem Chehalis River Upstream of the South Fork Chehalis River as a Result of Projected Climate Change



Source: PSU CE-QUAL-W2 model results

4 RESULTS

This analysis evaluated the effects of flood damage reduction measures and habitat restoration in terms of the change in habitat potential for spring-run Chinook salmon, fall-run Chinook salmon, coho salmon, chum salmon, and steelhead under current habitat conditions and under habitat conditions that are projected to occur in the future as a result of climate change. The structure of the habitat analysis is shown in Figure 2. Habitat potential refers to the ability of habitat to support a species in terms of potential abundance, capacity, productivity, or biological diversity. While the Chehalis EDT model evaluated all four of these biological measures, this report will discuss only the change in potential abundance of the species as a result of changes in the quantity and quality of habitat. Abundance refers to the equilibrium run size, which is the number of adult fish expected to return on average to the Basin under a modeled habitat condition (Appendix A, Box 2). Results are reported as both the relative change (percentage) and absolute change (numeric) in habitat potential between the modeled condition and the current habitat condition. Because of the large differences in overall abundance between the five modeled species, proportional changes are a better reflection of the effect of the action on the species than absolute changes.

Scale is an important aspect of this analysis; impacts of actions to populations at sub-basin scales can appear minor at the basin-scale in terms of the change in abundance. Basin-scale refers to change in habitat potential across the entire Chehalis Basin (including Grays Harbor) measured as the potential change in total abundance of the species across the Basin. Sub-basin scale refers to the change in abundance of the species returning to a sub-basin such as the Newaukum River or South Fork Chehalis River. While impacts of actions on individual populations or sub-basins may have small effects on Basin-wide abundance, the loss of individual populations could have significant impacts on spatial structure and biological diversity and thereby decrease resiliency to future climate change. Impacts of the actions on spatial structure, diversity, and resiliency have not yet been addressed in the Chehalis Basin Strategy, but can be evaluated using the Chehalis EDT model.

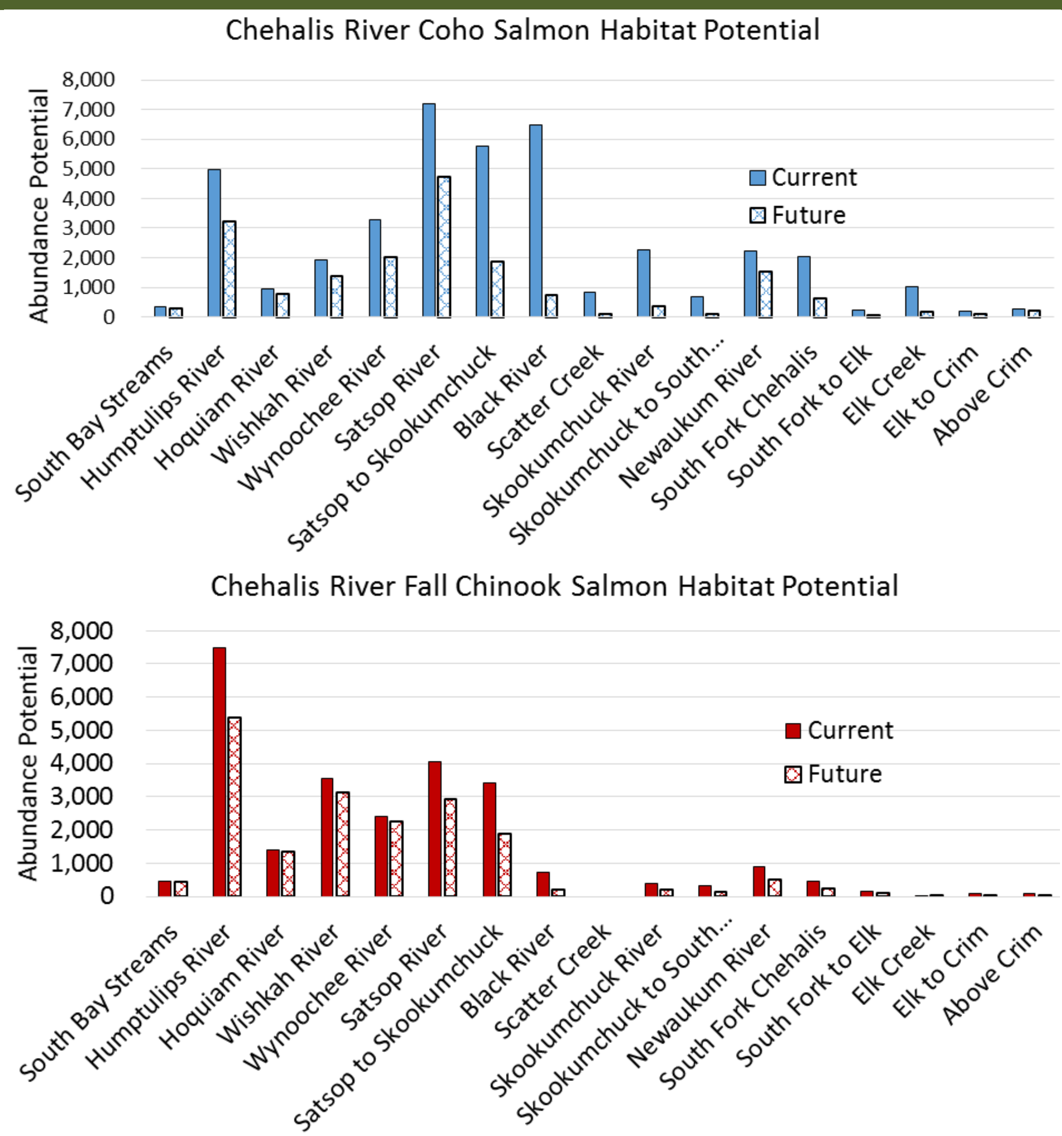
4.1 Current Habitat Potential

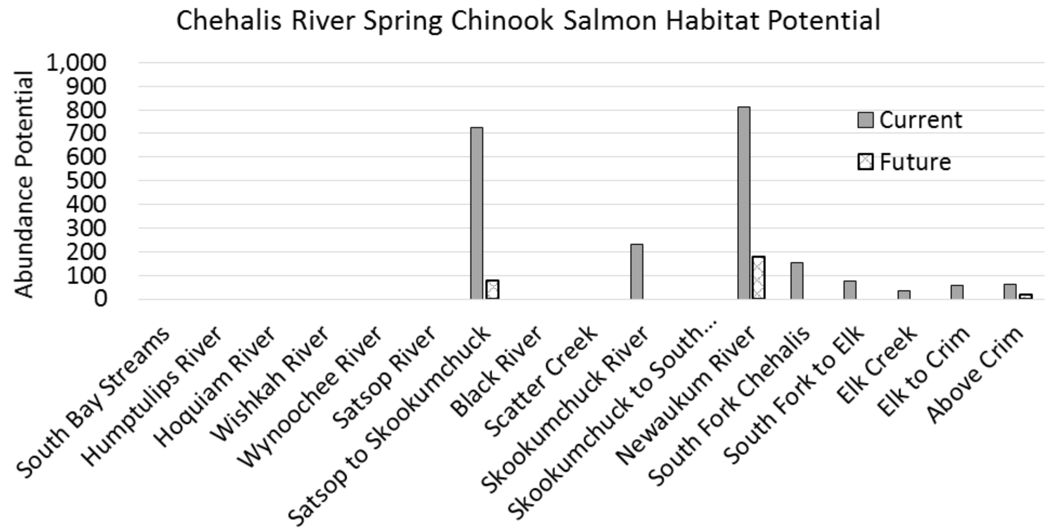
4.1.1 Key Findings

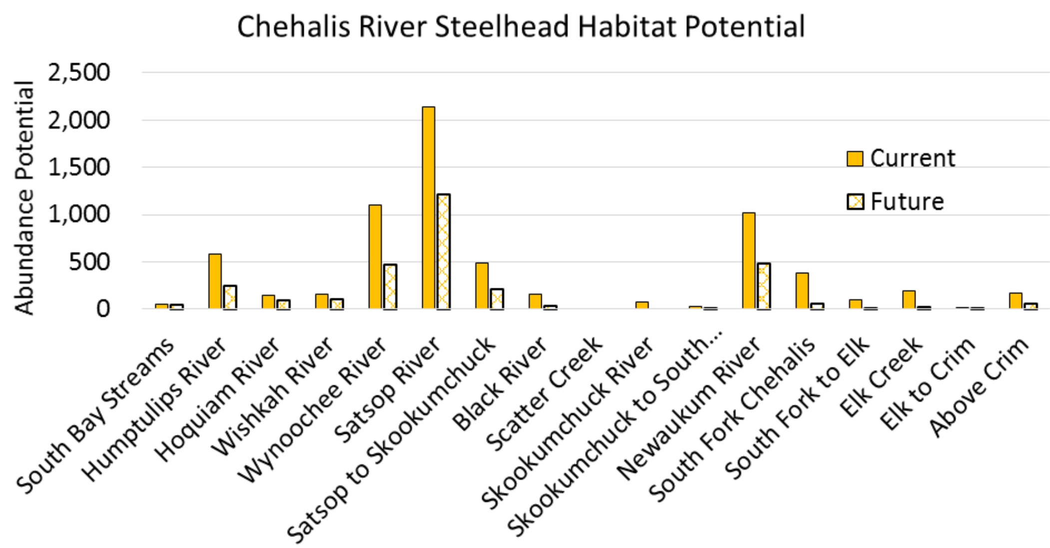
1. Based on the assumed fish distribution (Appendix A, Section 4.2.3), spring-run Chinook salmon habitat potential was concentrated in the upper portions of the Chehalis Basin above and including the Skookumchuck River (Figure 8). Chum salmon habitat potential was concentrated below the South Fork Chehalis River and largely below the Skookumchuck River. Habitat for fall-run Chinook salmon, coho salmon, and steelhead was more broadly distributed across the Chehalis Basin.

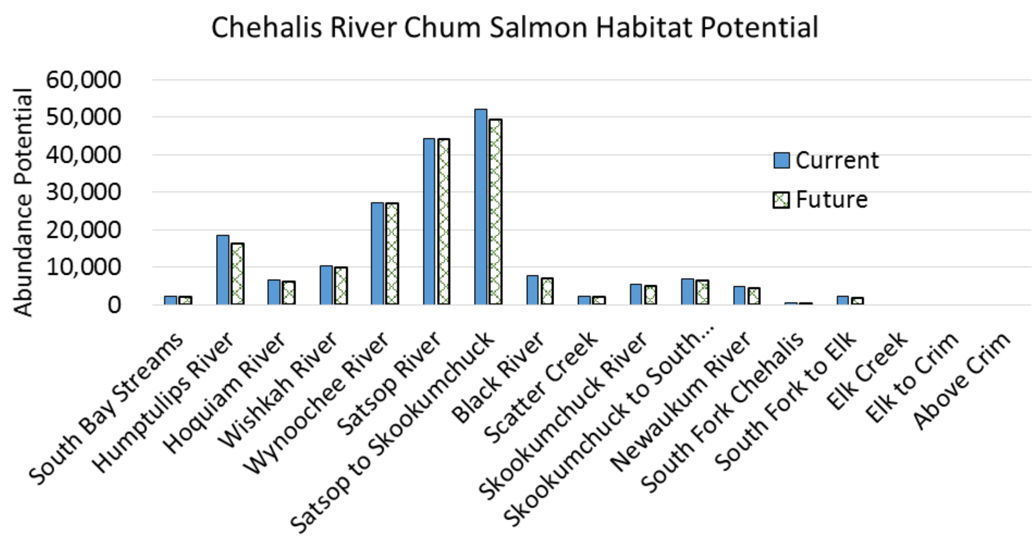
2. Modeled habitat potential for fall-run Chinook, coho, and chum salmon and steelhead in the Chehalis Basin was greatest in the lower part of the Basin, especially the very large sub-basins such as the Humptulips, Satsop, and Wynoochee (Figure 8).
3. Modeled habitat potential for all modeled species in the Chehalis Basin above the South Fork Chehalis River confluence was much less than that in the lower Chehalis Basin (Figure 8).
4. The distribution of habitat potential for the five modeled species across the Chehalis Basin computed by EDT compared favorably to the Washington Department of Fish and Wildlife (WDFW) observed distribution of fish abundance (Appendix A, Section 5).

Figure 8
Modeled Habitat Potential for Five Chehalis Basin Salmonid Species Under Current and Future Habitat Conditions




Chehalis River Spring Chinook Salmon Habitat Potential
Abundance Potential
1,000
900
800
700
600
500
400
300
200
100
0
Current
Future
South Bay Streams
Humptulips River
Hoquiam River
Wishkah River
Wynoochee River
Satsop River
Satsop to Skookumchuck
Black River
Scatter Creek
Skookumchuck River
Skookumchuck to South...
Newaukum River
South Fork Chehalis
South Fork to Elk
Elk Creek
Elk to Crim
Above Crim


Chehalis River Steelhead Habitat Potential
Abundance Potential
2,500
2,000
1,500
1,000
500
0
Current
Future
South Bay Streams
Humptulips River
Hoquiam River
Wishkah River
Wynoochee River
Satsop River
Satsop to Skookumchuck
Black River
Scatter Creek
Skookumchuck River
Skookumchuck to South...
Newaukum River
South Fork Chehalis
South Fork to Elk
Elk Creek
Elk to Crim
Above Crim


Chehalis River Chum Salmon Habitat Potential
Abundance Potential
60,000
50,000
40,000
30,000
20,000
10,000
0
Current
Future
South Bay Streams
Humptulips River
Hoquiam River
Wishkah River
Wynoochee River
Satsop River
Satsop to Skookumchuck
Black River
Scatter Creek
Skookumchuck River
Skookumchuck to South...
Newaukum River
South Fork Chehalis
South Fork to Elk
Elk Creek
Elk to Crim
Above Crim

4.1.2 Discussion

The five modeled species differ greatly in habitat potential across the Chehalis Basin and there are also large differences between sub-basins (Figure 8). Relative to spring-run Chinook salmon at the basin-scale, habitat potential for chum salmon is 88 times greater; habitat potential for coho salmon is 19 times greater; habitat potential for fall-run Chinook salmon 12 times greater; and habitat potential for steelhead is 3 times greater. The result of this is that relatively large proportional changes in spring-run Chinook salmon abundance because of a modeled action represent small numeric changes in abundance, while small proportional changes in chum salmon abundance result in large numeric changes in abundance.

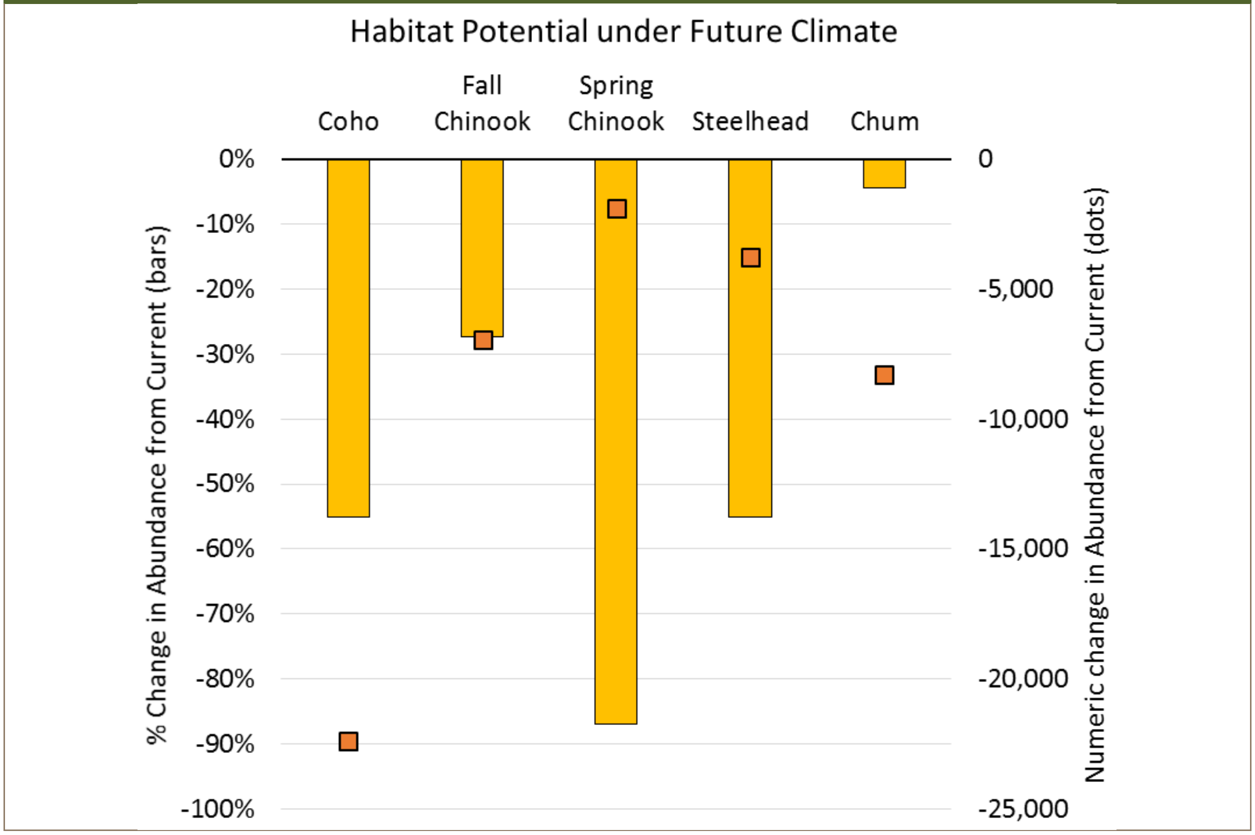
The habitat-based estimates of potential fish production in the Chehalis sub-basins were compared to the WDFW estimates of fish escapement based on expansion of redd counts and other observational data. The EDT habitat-based estimates of habitat potential for the five modeled species were generally similar to the WDFW fish population estimates (Appendix A, Section 5).

4.2 Habitat Potential under Future Climate Conditions

4.2.1 Key Findings

1. Independent of the flood damage reduction options and ASHA, modeled future climate conditions within the Chehalis Basin greatly decreased habitat potential in the Chehalis Basin for all five modeled species (Figure 9), primarily due to the increase in summer water temperature. Decreases in habitat potential were biologically significant at the basin-scale and for individual sub-basins.
2. The effect of future climate conditions on the modeled species depended on their distribution across the Basin and especially on their length of exposure to conditions in the Basin.
3. Spring-run Chinook salmon were most affected by future climate conditions. Overall habitat potential for spring-run Chinook salmon across the Chehalis Basin was reduced by 87% compared to the current condition and was totally eliminated for five of the eight modeled EDT populations (Figure 8).
4. The lowest proportional decreases in habitat potential under the modeled future conditions were for chum and fall-run Chinook salmon. These species experience conditions in the Chehalis Basin mainly in winter and would be less exposed to future increases in summer water temperatures.
5. In general, habitat in upper sub-basins were more negatively affected by climate change than were lower sub-basins, which further skewed habitat potential for the modeled species toward the lower Chehalis Basin under future conditions (Figure 8).

Figure 9
Change in Habitat Potential for the Five Modeled Salmonids Across the Chehalis Basin under Future Climate Conditions



4.2.2 Discussion

The changes in habitat conditions in the Chehalis Basin under projected future climate conditions resulted in significant reductions in habitat potential for spring-run Chinook salmon, coho salmon, fall-run Chinook salmon, and steelhead at both the basin-scale and for individual sub-basin populations; habitat potential for chum salmon was reduced to a lesser degree (Figure 9). The projected increase in temperature in the Chehalis Basin was a major driver of the climate effect in this analysis and is likely to negatively affect conditions for salmonids and other native species. Summer water temperature in much of the Chehalis system is currently high and has been identified as a major factor limiting salmon production (Smith and Wenger 2001). Model projections of future temperature in the Chehalis Basin (Van Glubt et al. 2016) indicate the likelihood of substantial increases in water temperature under climate change projections (Figure 7). While cold water seeps and springs can provide important temperature refugia for salmon (Torgersen et al. 1999; Ebersole et al. 2001) that may moderate climate effects, future increases in water temperature will exacerbate the underlying water temperature limitations of the Chehalis system for salmonids and other aquatic species.

Differences in climate change effects between species reflected differences in life history, length of exposure, and distribution across the Chehalis Basin. Spring-run Chinook salmon were most affected by future climate because they enter the Chehalis River as pre-spawning adults in the spring and remain over the summer prior to spawning in late summer and early fall. Overall abundance decreased by 89% while habitat potential in five of the eight modeled sub-basins was eliminated entirely under future climate (Figure 8). Throughout the modeling spring-run Chinook salmon were limited to a large degree by high summer and early fall water temperatures that reduced survival of pre-spawning adults. Increased temperature under future conditions further reduced survival and reduced overall habitat potential for the species. In contrast, chum salmon and fall-run Chinook salmon were relatively less affected by the future climate assumptions compared to other species due to their relatively short exposure to conditions in the Chehalis Basin because of their life histories. Both species return as adults in the fall just prior to spawning; juveniles emerge and emigrate the following spring. As a result, chum salmon and fall-run Chinook salmon have less exposure to high temperatures and other conditions associated with future climate compared to the other modeled species.

The current low abundance of spring-run Chinook salmon in the Basin, the large reduction in overall habitat potential under future climate, and the complete elimination of habitat potential in much of the Basin under projected future conditions call into question the persistence of spring-run Chinook salmon in the Chehalis Basin in the future without significant improvement in habitat conditions. The upper Chehalis Basin above Crim Creek, the Newaukum River, and a portion of the mainstem Chehalis River below the Skookumchuck River retained some habitat potential under future climate conditions that could form refuge areas that contribute to production in other areas in years of favorable ocean or freshwater conditions.

In general, habitat potential for upper sub-basins (above the Newaukum River) was negatively affected by future climate to a greater degree than lower sub-basins. Habitat potential in many of the salmonid populations in the upper Basin was greatly reduced or eliminated (Figure 8), resulting in an even larger proportion of the overall production in the Basin coming from the lower sub-basins under future climate conditions. Upper sub-basins were more strongly affected by climate change than lower sub-basins because in addition to the negative effects on habitat in each sub-basin, upper Basin areas were affected by warmer future water conditions in the mainstem Chehalis River during adult immigration, pre-spawn holding, and juvenile emigration life stages. For example, production of fish above Crim Creek was reduced not only by warmer future water conditions in the sub-basin but also by warmer water in the 108 miles of the Chehalis River mainstem below Crim Creek. An exception to this general observation was the large decline in habitat potential in the Black River (Figure 8). The Black River is a low gradient system with low water velocities and high water temperature under current conditions. Projected future warming exacerbated the adverse current conditions and reduced projected fish abundance.

4.3 Flood Retention/Flow Augmentation and Flood Retention Only Facilities

4.3.1 Key Findings

1. At the scale of the Chehalis Basin, the FRFA and FRO facilities resulted in a relatively small decrease in habitat potential for the five modeled species under current habitat conditions (Figure 10).
    a. In general, the FRFA impacts on habitat potential for the five modeled species were slightly less negative than the FRO impacts.
    b. The greatest reduction in habitat potential from the FRFA and FRO facilities was for spring-run Chinook salmon (3.8% reduction, FRO) while the least reduction in habitat potential was for fall-run Chinook salmon (0.3% reduction, FRO).
2. At the sub-basin scale, the effect of the FRFA and FRO facilities was much greater than at the basin-scale (Figure 11).
    a. Habitat potential for fish above Crim Creek with the FRFA facility was reduced by 97% for fall- and spring-run Chinook salmon, by 23% for coho salmon, and by 50% for steelhead (Figure 11a). Chum salmon were assumed to not be present in the Chehalis Basin above the South Fork Chehalis River.
        i. The FRFA reservoir inundated almost all spawning reaches above Crim Creek for fall- and spring-run Chinook salmon and eliminated nearly all habitat potential for these species.
        ii. Coho salmon had the least reduction in habitat potential above Crim Creek as a result of the FRFA facility (23% reduction). While some spawning habitat was eliminated by the reservoir, coho salmon were assumed to benefit from the expanded habitat for juvenile rearing in the reservoir.
        iii. Steelhead spawning habitat was also lost due to the FRFA reservoir but remained in reaches above the reservoir. However, it was assumed that steelhead did not use reservoirs as juvenile rearing habitat and did not benefit from juvenile rearing as coho salmon did.
    b. As a result of the FRO facility, spring- and fall-run Chinook salmon habitat potential above Crim Creek declined, but persisted because the mainstem Upper Chehalis spawning reaches were not eliminated as they were with the FRFA facility (Figure 11b).
        i. Coho salmon potential was reduced with the FRO facility to a greater degree than with the FRFA facility because juvenile coho salmon did not get the benefit of increased juvenile rearing provided by the FRFA reservoir.
        ii. Loss of steelhead habitat potential above Crim Creek under the FRO facility was similar to that under the FRFA facility. Under both facilities habitat above the reservoir footprint was retained but habitat within the reservoir footprint was lost or degraded.

3. Below the proposed facility site, habitat potential for coho salmon and fall-run Chinook salmon was reduced to a greater degree by the FRFA facility than by the FRO facility (Figure 11). The FRFA facility was assumed to reduce large wood and degrade channel form below the facility to a greater degree than the FRO facility, resulting in a greater negative effect on coho salmon and fall-run Chinook salmon.
4. Habitat potential for spring-run Chinook salmon below the FRFA facility increased appreciably from Crim Creek to Elk Creek compared to the current conditions baseline (Figure 11a). The increase in habitat potential was due to decreased summer water temperature below the FRFA facility as a result of cold water being released from the reservoir during summer and early fall (Figure 11a).
5. In contrast, water leaving the FRO facility in summer was warmer than under current conditions. As a result, habitat potential for spring-run Chinook salmon below the FRO facility declined compared to the current habitat potential (Figure 11b).
6. The combination of the flood retention facilities and climate change resulted in a large decrease in habitat potential for the five modeled species (Figure 12). Although almost all of the change shown in Figure 12 was due to future climate, the FRO and FRFA facilities added slightly to the negative effect of the future climate at the basin-scale.

Figure 10
Flood Retention Facilities Under Current Habitat and Climate Conditions

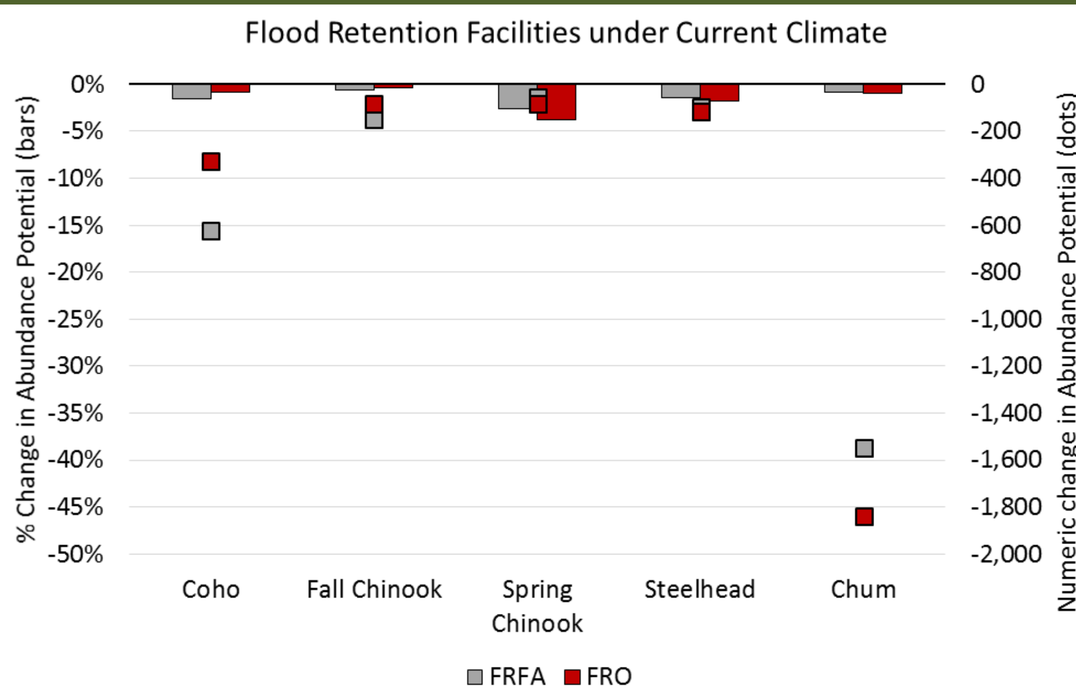


Figure 11
Flood Retention Facilities Relative to Current Habitat Potential

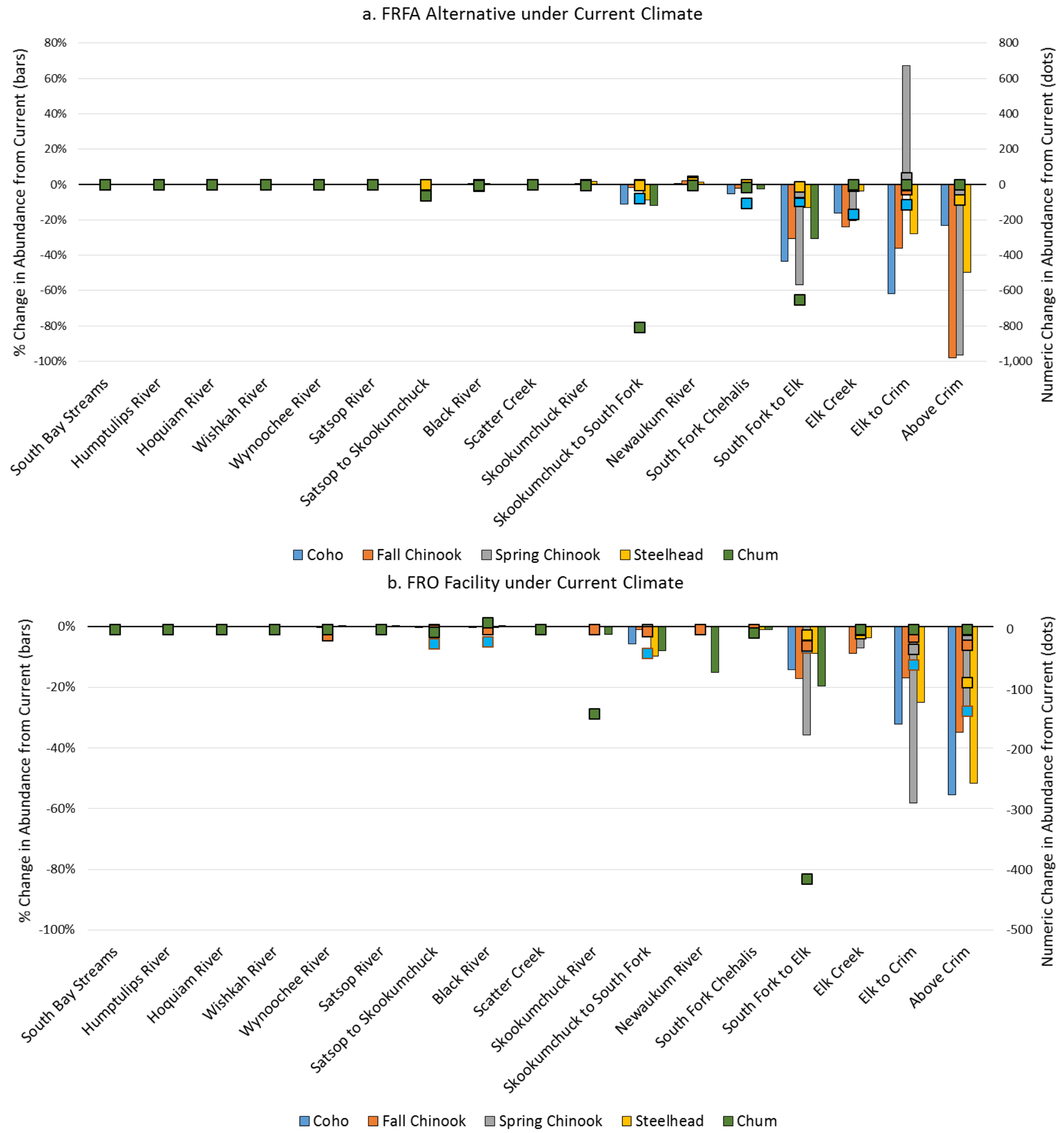
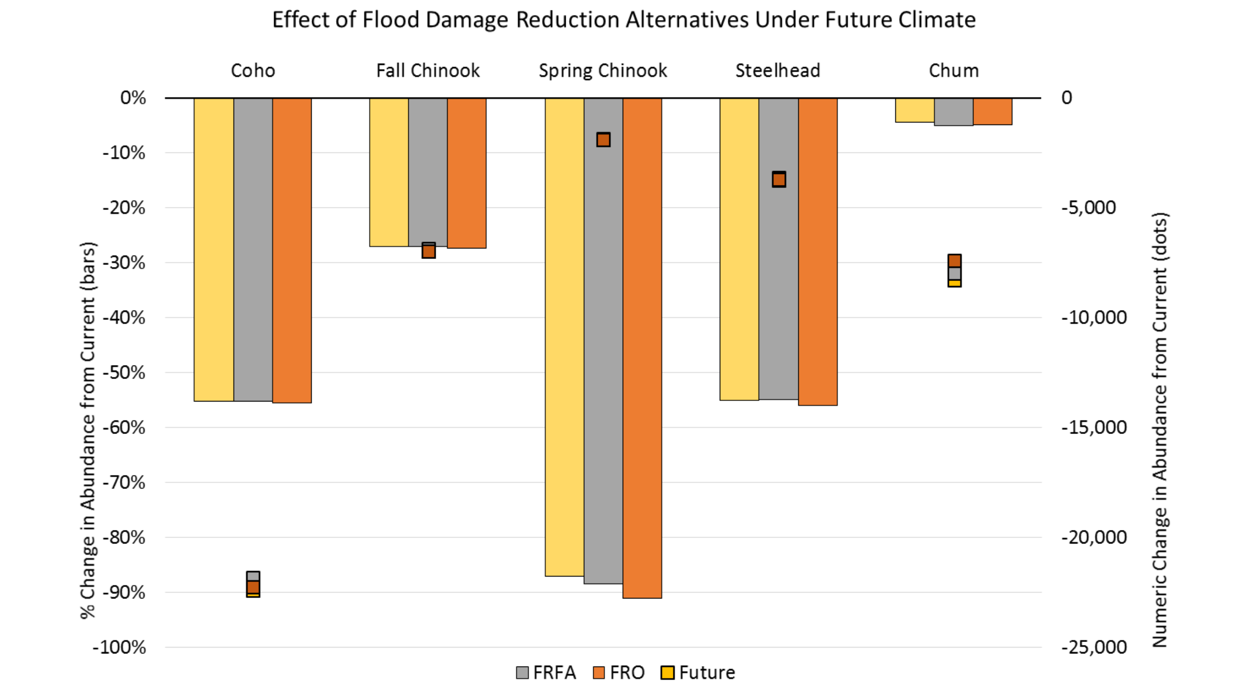


Figure 12
Flood Retention Facilities Under Future Climate Conditions Relative to Current Habitat Potential



4.3.2 Discussion

The FRO and FRFA facilities had relatively small impacts on Basin-wide habitat potential for the five modeled species under current habitat conditions (Figure 10). This was because the area above Crim Creek (the area most directly affected by the FRO and FRFA facilities) currently contributes a relatively small portion of the Basin-wide habitat potential for the five modeled species. The current habitat potential for the five modeled species above Crim Creek as a proportion of the total Basin-wide habitat potential was estimated to be 0.7% for coho salmon, 0.3% for fall-run Chinook salmon, 3% for spring-run Chinook salmon, 2.5% for steelhead, and 0.0% for chum salmon. In short, relatively little of the basin-level habitat potential for the five modeled species was affected by the FRO and FRFA facilities.

Chum salmon distribution did not extend above the South Fork Chehalis River and only experienced small negative effects of the facilities downstream of the dam site.

On the other hand, the FRO and FRFA facilities greatly reduced habitat potential for Chinook salmon, coho salmon, and steelhead (Figure 11) above Crim Creek. Fall- and spring-run Chinook salmon habitat above Crim Creek was effectively eliminated by the FRFA facility (Figure 11a). Most of the Chinook salmon spawning habitat above Crim Creek is in the mainstem Chehalis River reaches below the confluence of the East and West Forks of the Chehalis River. With the FRFA facility, these areas would be inundated by the reservoir, eliminating most Chinook salmon spawning above Crim Creek.

Coho salmon spawning habitat was also reduced above Crim Creek due to the FRFA reservoir, but to a lesser degree than the other species (Figure 11a). While coho salmon spawning habitat in the mainstem Chehalis River above Crim Creek was eliminated by the FRFA reservoir, habitat that supported fish production remained in the streams above the reservoir footprint. Juvenile coho salmon produced in the remaining habitat benefited from the large expanse of downstream rearing habitat in the reservoir; this served to moderate the negative effect of the FRFA facility on coho salmon above Crim Creek.

A significant amount of steelhead spawning habitat was eliminated by the FRFA reservoir as well, but habitat remained in the streams above the FRFA reservoir footprint that continued to provide habitat potential. However, the FRFA facility had a greater negative effect on steelhead habitat potential above Crim Creek compared to coho salmon (Figure 11a). This was because it was assumed that steelhead would not use reservoir habitat for juvenile rearing, unlike coho salmon. Hence, steelhead did not get the benefit of increased juvenile habitat in the reservoir that moderated the negative effect of the FRFA facility on coho salmon.

The FRO facility significantly degraded habitat above Crim Creek due to clearing of riparian forest, which increased temperature and sedimentation and reduced wood loading. These changes reduced habitat potential for Chinook salmon, coho salmon, and steelhead (Figure 11b). However, in contrast to the FRFA facility, the FRO facility retained Chinook salmon spawning habitat in the mainstem reaches and habitat potential above Crim Creek. Coho salmon habitat was also degraded with the FRO facility, but there was no increase in potential juvenile rearing habitat as occurred in the FRFA reservoir (Figure 11b).

The FRFA facility had a positive effect on habitat potential for spring-run Chinook salmon below the facility down to Elk Creek (Figure 11a) because of the release of cold hypolimnetic water from the facility during summer and early fall. The cooler summer water below the FRFA facility increased habitat potential for spring-run Chinook salmon in the Crim Creek to Elk Creek section of the mainstem Chehalis River by about 60% compared to current habitat conditions. This decrease in water temperature increased habitat potential for the pre-spawning and spawning life stages and resulted in an overall increase in habitat potential for spring-run Chinook salmon below the FRFA facility.

It is important to note that the positive effect on spring-run Chinook salmon below the FRFA facility calculated by EDT represents a change in habitat potential; while the assumption in EDT is that spring-run Chinook salmon would take advantage of the cooler water, it is possible that behavioral issues not considered in this analysis could prevent them from occupying the higher potential habitat below the dam. The Chehalis River between Crim Creek and Elk Creek currently supports very small numbers of spawning spring-run Chinook salmon (Figure 8). Dead pre-spawning adults are rarely observed in the area during summer indicating that fish likely avoid the area currently because of high summer water temperatures. The prediction from EDT is that the release of cold water from the FRFA facility could provide conditions to support pre-spawning adult spring-run Chinook salmon in the Crim Creek to Elk Creek section, improve adult spawning survival, and increase the amount of suitable habitat for the species Basin-wide. Though the proportional increase shown in Figure 11a is comparatively large, it represents change to a small current habitat potential resulting in a small increase (38 fish) in the projected number of spring-run Chinook salmon. The positive effect of the cold-water releases from the FRFA facility diminished below Elk Creek as the water warmed and negative effects of the facility on materials transport outweighed the effect of reduced water temperature.

Under future climate the effect of the FRFA and FRO facilities was slightly less than under the current habitat condition. This was because future climate reduced habitat potential above Crim Creek, leaving less habitat potential to be impacted by the flood reduction facilities. Because the current habitat potential above Crim Creek is low, the reduction in habitat potential due to the flood retention facilities under future climate was also relatively small.

4.4 Restorative Flood Protection

4.4.1 Key Findings

1. Except for chum salmon, RFP significantly increased habitat potential for the modeled species compared to the potential under the current conditions baseline (Figure 13).
2. The greatest positive effect of RFP was on habitat potential for spring-run Chinook salmon. The restoration of the riparian forest, channel structure, and floodplain resulting from RFP decreased water temperature above the Newaukum River. This decrease benefited all modeled species to varying degrees, with the greatest benefit to spring-run Chinook salmon.
3. Coho salmon habitat potential benefited from the increase in large wood along with floodplain and off-channel habitats created by RFP. Potential coho salmon abundance increased substantially as a result of the RFP (Figure 13).
4. The type of habitats created by RFP was less important to fall-run Chinook salmon and steelhead resulting in a smaller benefit to these species (Figure 13).
5. While future climate conditions reduced the positive impacts of RFP, the action substantially countered the adverse effect of future climate conditions (Figure 14). Spring-run Chinook salmon was the only species that showed a positive benefit from RFP under future climate compared to current habitat potential.

Figure 13
Effect of Restorative Flood Plain on Salmonids at the Chehalis Basin Scale Under Current Climate

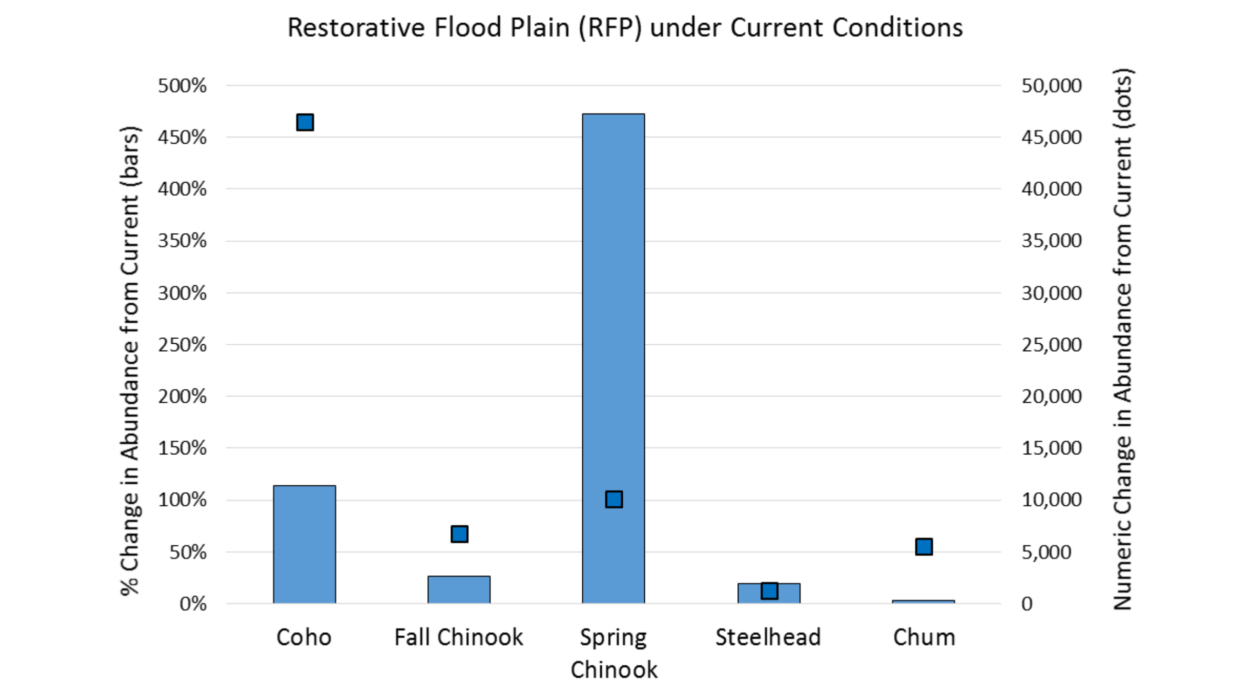
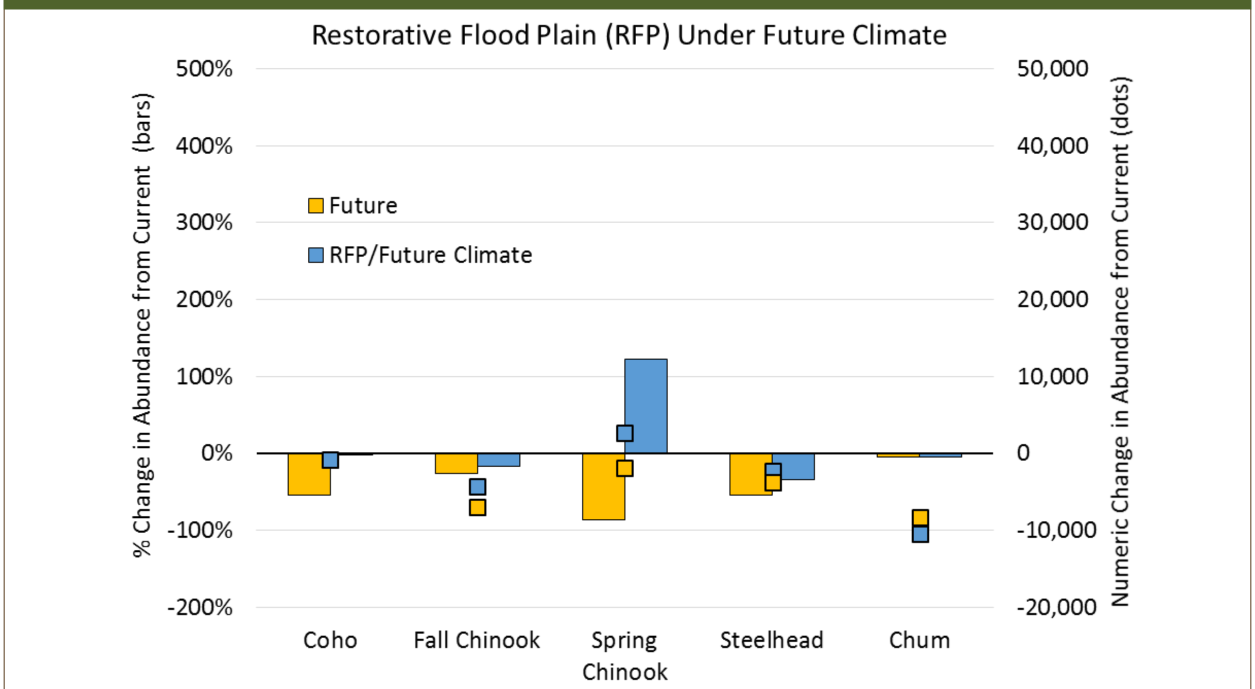


Figure 14
Effect of Restorative Flood Plain on Salmonids at the Chehalis Basin Scale Under Future Climate



4.4.2 Discussion

RFP would substantially alter current habitat conditions in the Basin above the Newaukum River (City of Chehalis) and restore much of the historical character of the river through its focus on riparian and floodplain areas in valley bottom reaches. The greatest effect of RFP would be in areas with broad floodplains including the mainstem Chehalis River, the lower reaches of the Newaukum River, South Fork Chehalis River, and smaller tributaries (Abbe et al. 2016). Higher gradient areas of the tributaries and the upper watershed, such as that above Crim Creek, have more confined floodplains and would be less affected by RFP.

Habitat potential in the mainstem Chehalis River above the Newaukum River confluence is currently low (Figure 8) as a result of high summer water temperature, lack of wood and other structural elements, and a channel confined by incision. The RFP was assumed to address many of these limitations. It was assumed to restore river-floodplain connectivity through extensive restoration of large wood structure that would trap sediment and aggrade the channel up to the present level of the floodplain (Abbe et al. 2016). The riparian and floodplain forest would be restored to near-historic conditions, creating shade, reducing water temperature, and increasing the delivery of large wood to the channel.

The analysis indicated that the changes to aquatic habitat from the RFP would benefit spring-run Chinook salmon; habitat potential increased almost five-fold for that species compared to the current conditions baseline (Figure 13). The species is currently limited in much of the RFP area by high water temperature and other issues. The extended fresh water adult pre-spawning life stage of spring-run Chinook salmon makes them vulnerable to high water temperature and sensitive to actions that reduce water temperature, like RFP. RFP was assumed to lower water temperature throughout much of the assumed range of spring-run Chinook salmon due to increased riparian shading, increased channel complexity, and reconnection of the river and floodplain.

RFP also benefited coho salmon and more than doubled their habitat potential compared to the current conditions baseline (Figure 13). Coho salmon habitat potential was increased by the added low gradient, floodplain, and off-channel habitat associated with RFP. Off-channel and floodplain ponds and wetlands provide winter refugia for juvenile coho salmon (Bustard and Narver 1975; Henning et al. 2007; Lestelle 2007). Much of this type of habitat has been eliminated from the mainstem Chehalis River above the Newaukum River resulting in part in the current low abundance of coho salmon in this section of the river.

Other species received less benefit from RFP because of differences in habitat preferences and spatial distribution (Figure 13). Fall-run Chinook salmon spend less time in the Chehalis system than spring-run Chinook salmon and coho salmon and do not utilize floodplain and off-channel areas provided by RFP to the same degree as coho salmon. Because fall-run Chinook salmon emigrate before high water temperature becomes an issue, they did not greatly benefit from the decreased summer water temperature provided by RFP. Likewise, steelhead habitat potential did not greatly increase as a result of RFP because they are not drawn to off-channel and floodplain habitat and are generally distributed higher in the system through much of their juvenile residency in the Chehalis River. Most of the Chehalis River chum salmon production is distributed downstream of the Newaukum River and was largely unaffected by RFP.

Future climate conditions greatly reduced the positive effect of RFP on habitat potential relative to the current conditions baseline (Figure 14). However, RFP reduced the temperature increase associated with future climate and added large wood, riparian forest, and increased channel complexity; these changes moderated, but did not eliminate, the negative effects of future climate. Areas outside the RFP footprint did not benefit from the RFP and received the full effect of modeled future climate conditions. The increase in habitat potential for spring-run Chinook salmon due to RFP decreased under future climate, but was still more than double the potential under the current conditions baseline. RFP appreciably moderated the negative effect of future climate on coho salmon potential, although the resulting habitat potential was reduced compared to the current conditions baseline. Because fall-run Chinook salmon, chum salmon, and steelhead did not greatly benefit from the habitat changes produced by RFP, they were most strongly reduced by future climate despite RFP (Figure 14).

4.5 Aquatic Species Restoration Plan

4.5.1 Key Findings

1. Habitat changes assumed as part of the four ASHA alternatives provided substantial improvements in habitat potential for the five modeled species (Figure 15).
2. The Low60 and High60 scenarios provided greater habitat benefits than Low20 and High20 scenarios, indicating that the effectiveness of restoration was more important than the spatial extent of restoration outside managed forests.
3. Spring-run Chinook salmon benefited the most from the ASHA because of reductions in summer water temperature caused by improved riparian conditions. Increases in habitat potential for spring-run Chinook salmon with the ASHA ranged from 96% (Low20) to 715% (High60) compared to the current habitat potential (Figure 15).
4. Habitat potential for coho salmon increased from 56% (Low20) to 236% (High60) compared to the current conditions baseline (Figure 15).
5. Fall-run Chinook salmon and chum salmon showed the least response to habitat restoration (Figure 15) because of their limited freshwater residency compared to other species.
6. Steelhead habitat potential increased from 32% (Low20) to 114% (High60) under the ASHA restoration (Figure 15).
7. Climate change appreciably reduced the effect of the ASHA relative to their benefits under current climate (Figure 16). For example, the maximum increase in habitat potential for spring-run Chinook salmon under High60 was 255% under future climate compared to 715% under current climate.
8. Habitat restoration on the scale envisioned under ASHA provided significant moderation of climate change effects (Low20) or resulted in a net positive change in habitat potential in the

face of climate change (Low60, High20, and High60) compared to the current conditions baseline (Figure 16).

Figure 15
ASHA Under Current Climate Compared to the Current Conditions Baseline

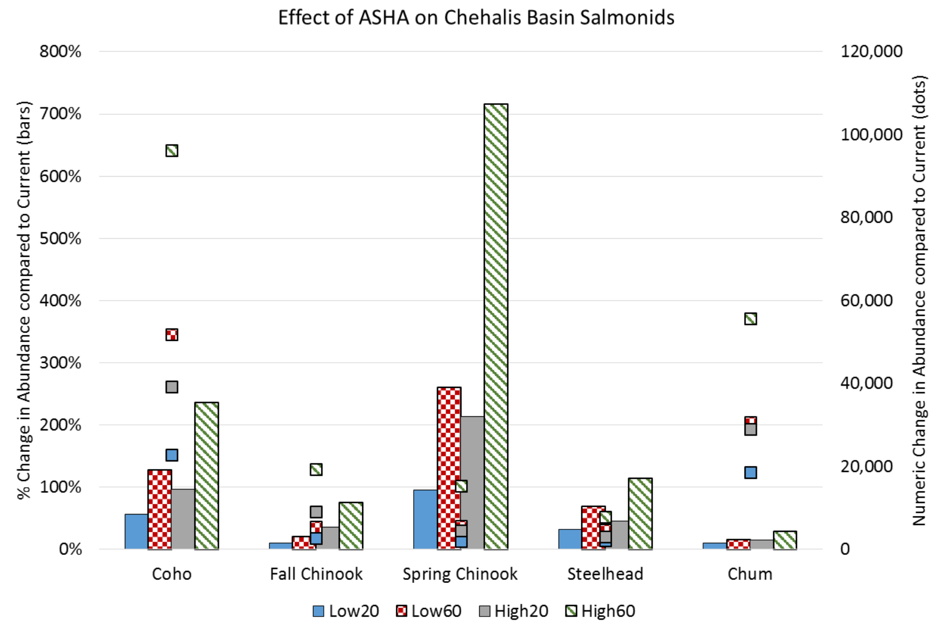
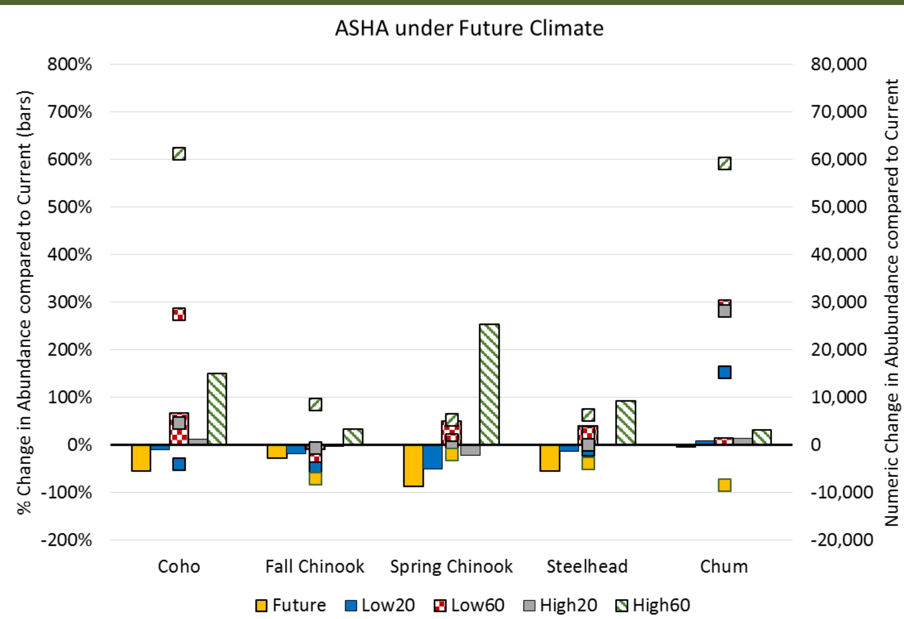


Figure 16
ASHA Under Future Climate Compared to the Current Conditions Baseline



4.5.2 Discussion

The ASHA restoration was significant in scale and extent and improved conditions across much of the Chehalis Basin. The four scenarios differed in regard to spatial extent of restoration outside managed forest (Low and High) and the assumed effectiveness of riparian restoration to affect aquatic habitat attributes (20% and 60%). ASHA restoration was greatest in the managed forest areas where all reaches received the riparian restoration treatment. All four scenarios assumed maturation and improvement of riparian conditions across all managed forest areas (48% of modeled stream miles) and in the selected reaches of non-managed forest areas (9% under Low scenarios and 32% under High scenarios). The ASHA scenarios provided a range of riparian effectiveness that substantially improved a number of key environmental conditions across the Basin that contributed to changes in habitat potential for the modeled species (Appendix A, Section 6.1).

The four ASHA alternatives substantially increased the habitat potential for the modeled species under current climate conditions (Figure 15). Compared to the current conditions baseline, habitat potential increased from a minimum of 10% for chum salmon (Low20) to a maximum of 715% for spring-run Chinook salmon (High60). Fall-run Chinook salmon and chum salmon showed the least response to ASHA because of their relatively short fresh-water residency compared to the other modeled species.

Spring-run Chinook salmon showed the greatest response to the ASHA; habitat potential increased more than seven-fold under the High60 scenario compared to the current conditions baseline (Figure 15). This improvement was largely due to improved survival of the pre-spawning and spawning life stages because of the reduction in summer water temperature associated with improved riparian conditions under the ASHA. Habitat potential for coho salmon more than doubled compared to the current conditions baseline under the High60 scenario as a result of the increase in large wood, decreased temperature, and improved channel complexity.

The proportional benefit of the ASHA was greater in sub-basins in the upper Chehalis Basin compared to those in the lower Basin. This was because most of the stream miles above the South Fork Chehalis River are in managed forest areas where maturation and improvement in riparian conditions was assumed in all stream reaches under the ASHA alternatives. Sub-basins lower in the system had a greater proportion of non-managed forest area where less restoration was applied based on reach selection criteria (Low or High). In addition, the restored habitat in the upper sub-basins was extended by the area of downstream mainstem habitat that also received the restoration treatment. For example, restoration of habitat in the upper Chehalis River above Crim Creek also benefited from restoration of the 108 miles of mainstem habitat below Crim Creek. Lower sub-basins such as the Satsop and Wynoochee had little or no associated improvements to mainstem habitat that added to restoration in the sub-basins.

Future climate conditions considerably reduced the effects of the ASHA on habitat potential for the five modeled species (Figure 16). However, the Low20 and High20 scenarios provided substantial compensation for the changes associated with future climate, while the Low60 and High60 alternatives appreciably increased habitat potential for coho salmon, fall- and spring-run Chinook salmon, and steelhead relative to current conditions, even in the face of future climate conditions. These findings imply that, in the face of expected future climate, habitat restoration needs to be pervasive across the Chehalis Basin to maintain current abundance of coho salmon, fall- and spring-run Chinook salmon, and steelhead, and must be both extensive and highly effective to meet management goals of increasing fish production in the Chehalis Basin.

4.6 Combined Flood Damage Reduction Facilities and Aquatic Species Restoration Plan

4.6.1 Key Findings

1. Both the FRFA (Figure 17) and FRO (Figure 18) facilities appreciably reduced the benefits of the ASHA restoration, although the overall change remained significantly positive compared to the habitat potential under current climate conditions (compare Figure 17 and Figure 18 to Figure 15).
2. When habitat potential for the modeled species was increased as a result of the ASHA, the FRFA (Figure 19) and FRO (Figure 20) facilities had an appreciably greater negative impact on the modeled species at the basin-scale than they did under current habitat conditions without the ASHA (compare Figure 19 and Figure 20 to Figure 10).
3. With the ASHA, the FRFA facility (Figure 19) had an appreciably greater negative effect on habitat potential for all five modeled species compared to the FRO facility (Figure 20). Without the ASHA, the two facilities had similar, and much smaller, impacts on habitat potential (Figure 10).
4. Without the flood damage reduction facilities, the Low20 restoration scenario moderated the effects of future climate conditions (Figure 16). However, when combined with the flood damage reduction facilities, the net result was a reduction in habitat potential for all modeled species except for chum salmon compared to the current habitat potential (Figure 21 and Figure 22).
5. Under future climate conditions, and with the flood retention facilities, the Low20 restoration resulted in a net decrease in habitat potential for all species except chum salmon compared to current conditions. The High60 restoration increased habitat potential for all five modeled species when combined with the FRO (Figure 21) or the FRFA (Figure 22) and climate change, although the positive change was reduced compared to the ASHA without the flood damage reduction actions.

Figure 17
Flood Reduction/Flow Augmentation Facility with ASHA Under Current Climate Conditions Compared to the Current Baseline

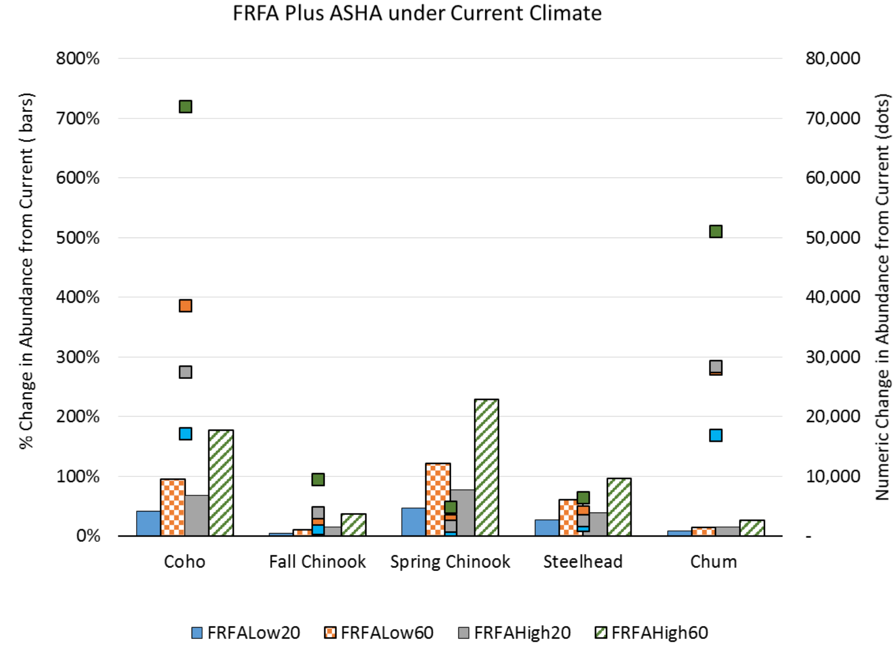


Figure 18
Flood Reduction Only Facility with ASHA Under Current Climate Conditions Compared to the Current Conditions Baseline

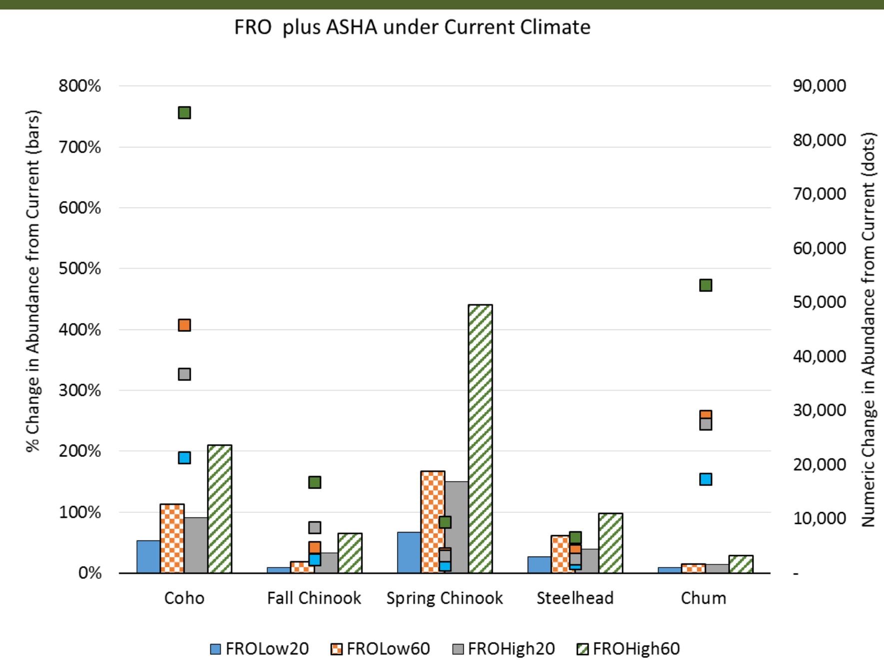
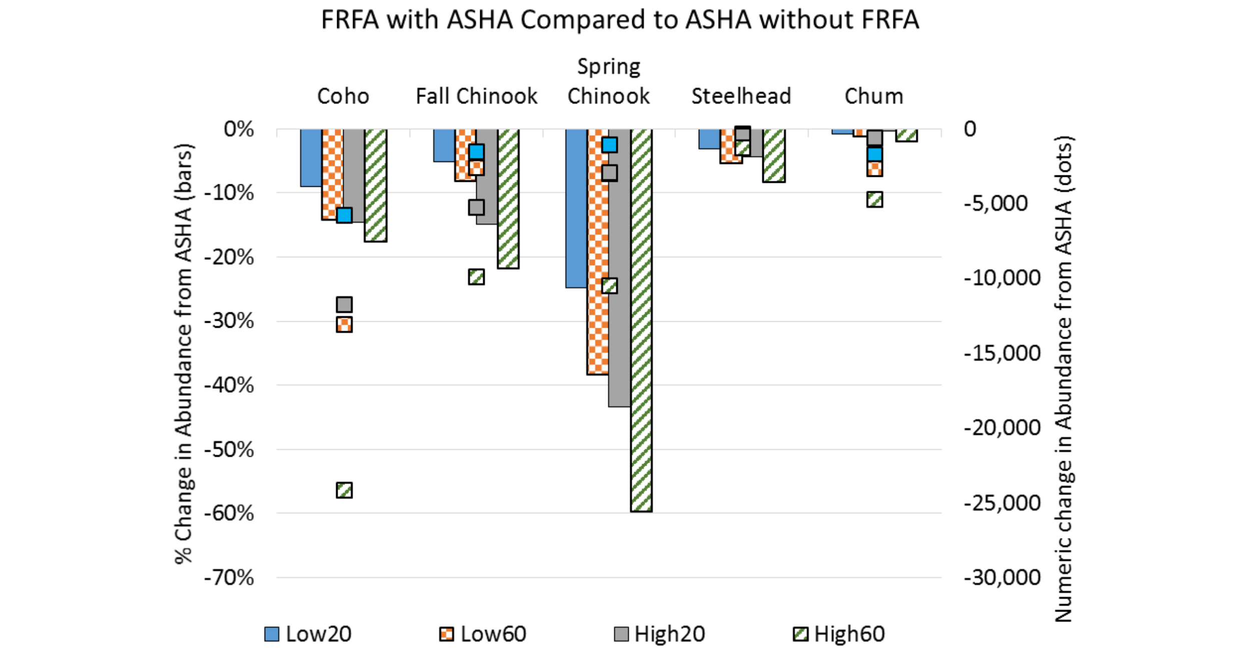
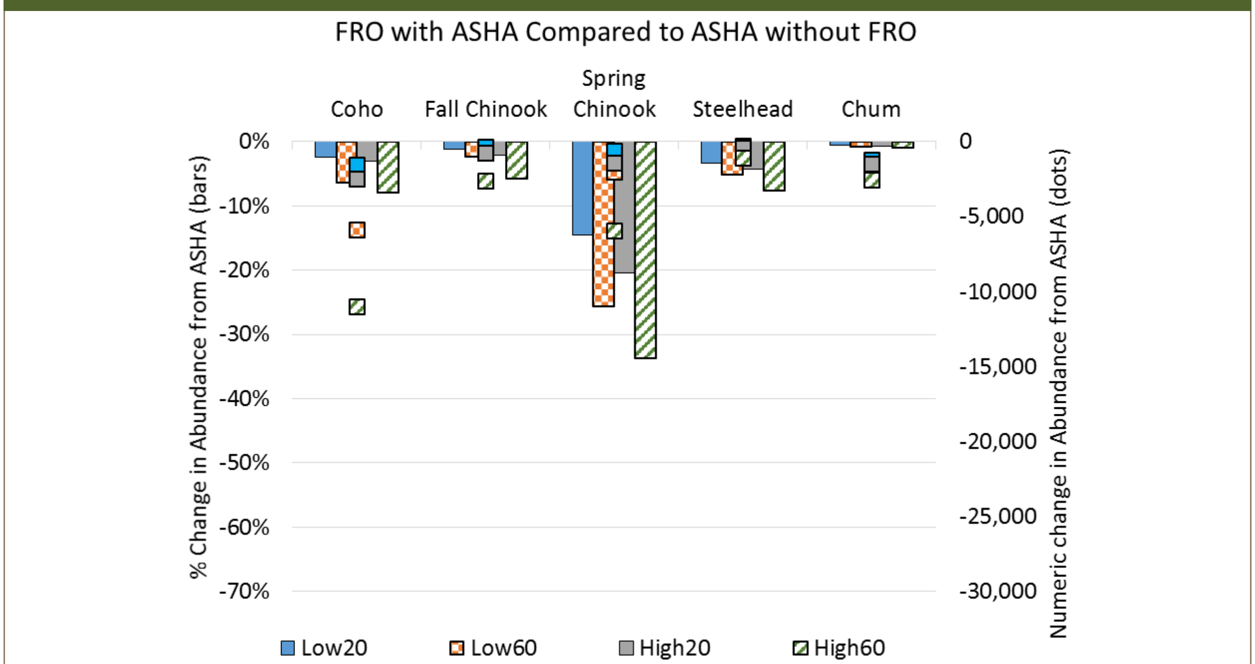


Figure 19
Flood Retention/Flow Augmentation Facility compared to the ASHA Under Current Climate



Note:
The base condition has been changed to the ASHA.

Figure 20
Flood Reduction Only Facility with the ASHA Under Current Climate



Note:
The base condition has been changed to the ASHA.

Figure 21
Flood Reduction/Flow Augmentation with ASHA at the Chehalis Basin Scale under Future Climate Conditions Compared to the Current Conditions Baseline

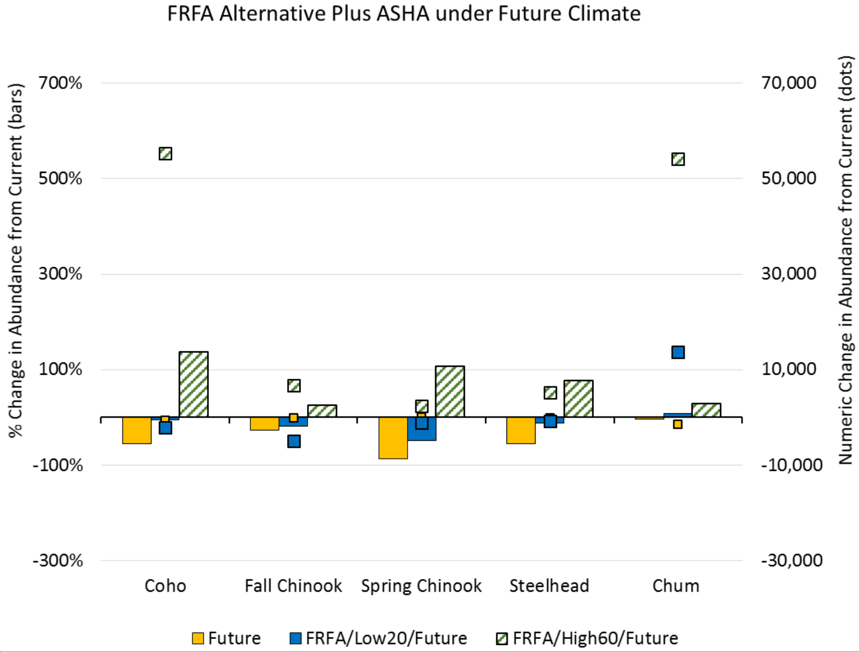
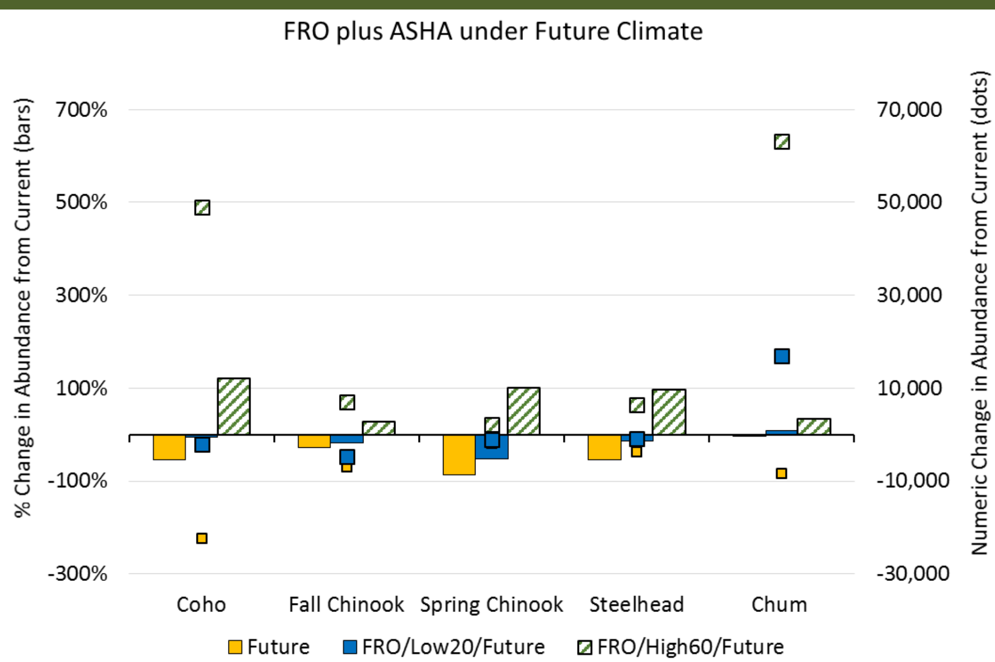


Figure 22
Flood Reduction Only Facility with ASHA under Future Climate Conditions Compared to the Current Conditions Baseline



4.6.2 Discussion

Improvement in habitat conditions because of the ASHA[2] altered the projected effect of the flood damage reduction facilities. With ASHA restoration, the negative effect of the FRFA (Figure 19) and FRO (Figure 20) facilities on habitat potential was appreciably greater compared to their effect under current habitat conditions (Figure 10). This was because the current biological value of the habitat above the facilities is relatively low due to habitat degradation associated with logging; under ASHA the habitat was appreciably restored as a result of maturation of riparian forests within managed forest areas. Consequently, degradation of the improved habitat due to the FRFA and FRO facilities had a much greater impact on basin-level habitat potential for the five modeled species—in effect, there was more to lose as a result of the facilities if the biological value of the affected habitat increased over time.

The increased negative impact of the FRFA and FRO actions in combination with ASHA reflects a general result seen in this analysis. The effect of the flood damage reduction actions depends on the biological value of the habitat that is potentially lost or degraded as a result of the facilities. For example, future climate (with no restoration) reduced the relatively small habitat potential that currently exists above Crim Creek. As a result, the impact of the facilities decreases slightly under future climate compared to current conditions because the habitat degraded by the facilities had less biological value (Section 4.3.2). On the other hand, if habitat in the upper Basin was improved as a result of maturation of riparian areas in managed forest areas under ASHA, then the biological value of the habitat degraded by the facilities increased and the loss of that habitat due to the FRFA or FRO facilities had a much greater negative effect on the modeled species.

Future climate conditions decreased the net positive changes in habitat potential under ASHA in combination with the FRFA and FRO facilities. While the Low20 alternative under current conditions without the flood retention facilities appreciably increased habitat potential for all five modeled species (Figure 15), the negative effects of the FRFA (Figure 21) and FRO (Figure 22) facilities plus climate change eliminated the positive effect of the Low20 restoration and resulted in a net decrease in habitat potential for the modeled species at a basin-scale. Although the overall effect was negative, the Low20 alternative should not be discounted as it appreciably moderated the negative effects of climate change and the flood retention facilities. The High60 alternative produced a net positive change in habitat potential for all five modeled species when combined with climate change and the flood retention facilities. However, climate change and flood retention facilities greatly diminished the positive effect of the High60 alternative. For example, under current conditions without a flood retention facility, the High60 alternative increased habitat potential for spring-run Chinook salmon by over 700% (Figure 15). In the presence of climate change and the flood retention facilities, the positive effect of the High60 alternative on spring-run Chinook salmon habitat potential was reduced to about 100% under either flood retention facility compared to the current habitat conditions (Figure 21 and Figure 22). This reinforces the conclusions that habitat restoration that was pervasive across the Chehalis Basin and effective in improving habitat conditions for the five modeled species was required to counter the

[2] For this combination only the Low20 and High60 alternatives have been evaluated.

decrease in habitat potential projected to occur as a result of climate change in combination with a flood retention facility.

4.7 Combined Restorative Flood Protection and Habitat Restoration

4.7.1 Key Findings

1. The addition of ASHA outside the RFP footprint further increased the positive change in habitat potential associated with the RFP for the five modeled species (Figure 23).
2. The effect of ASHA plus the RFP was especially large for spring-run Chinook salmon.
3. Although future climate conditions reduced the gain in habitat potential from the RFP and habitat restoration scenarios (Figure 24), the net effect of the combination of the RFP and the Low20 or High60 restoration scenarios was a substantial increase in habitat potential under future climate conditions, especially for spring-run Chinook salmon and coho salmon, compared to the habitat potential under current conditions.

Figure 23
RFP Plus ASHA Under Current Climate Conditions Compared to the Current Conditions Baseline

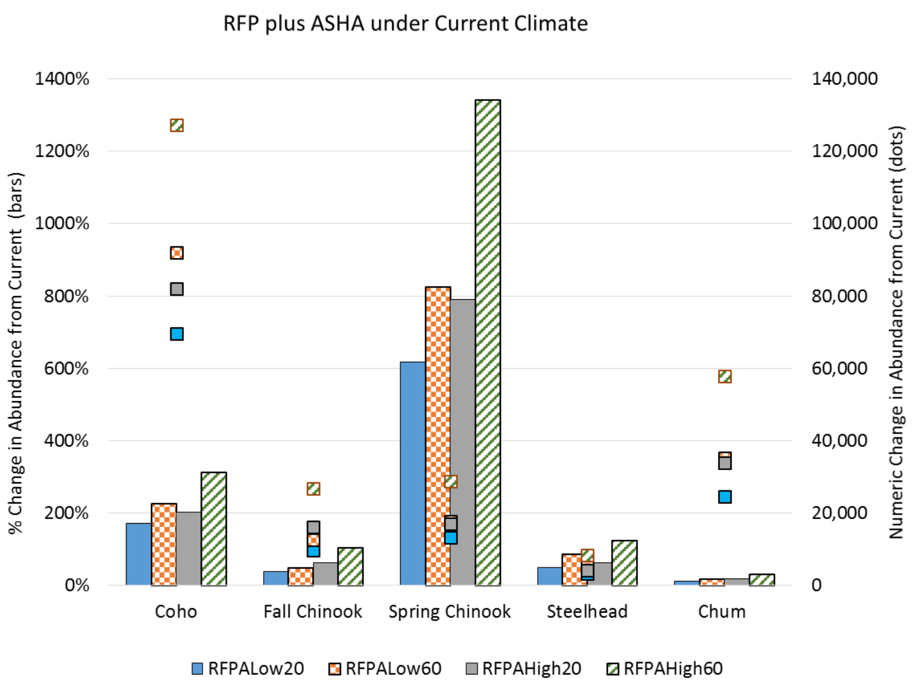
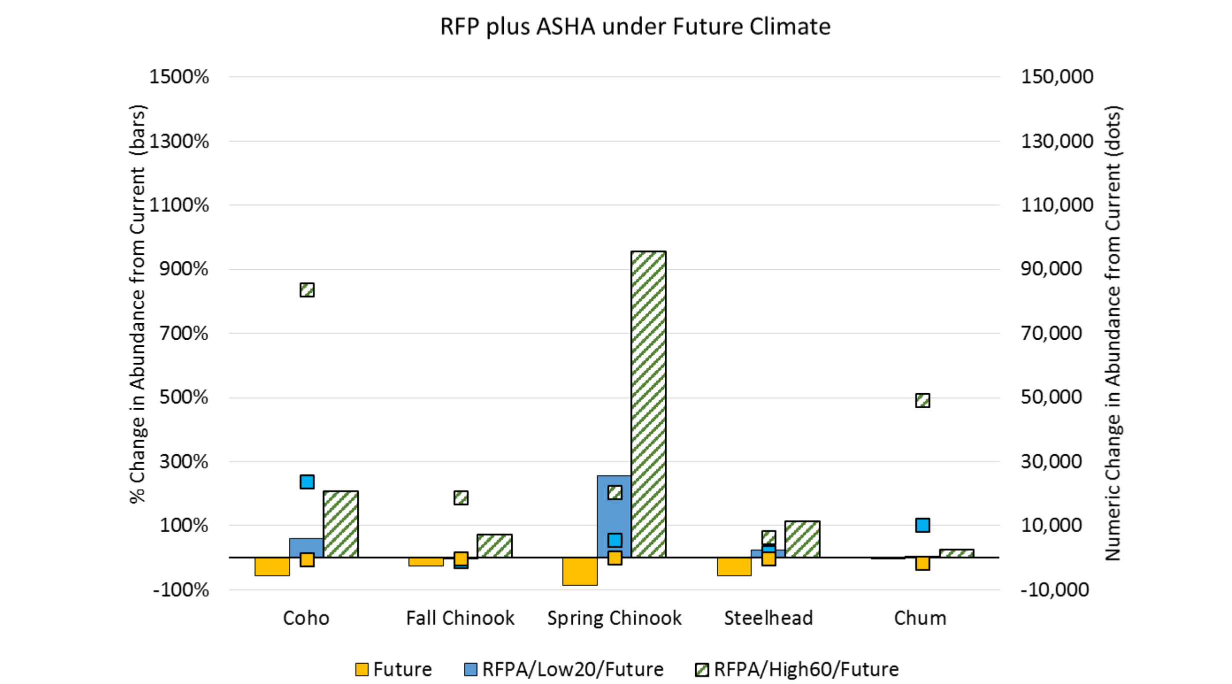


Figure 24
RFP With ASHA Under Future Climate Conditions Compared to the Current Conditions Baseline



4.7.2 Discussion

The RFP alternative was assumed to restore the mainstem and lower tributaries above and including the Newaukum River to near-historic conditions, while the Low and High ASHA scenarios were assumed to affect riparian conditions outside the RFP footprint. The combination of the RFP and the ASHA resulted in substantial increases in habitat potential throughout the Chehalis Basin for all five modeled species, with the greatest effect accruing to habitat potential for spring-run Chinook salmon (Figure 23). Compared to the current condition, habitat potential for spring-run Chinook salmon in the Chehalis Basin was increased 13-fold under the combination.

Under future climate conditions, habitat potential under the combination of RFP and ASHA (Figure 24) was substantially reduced, but was still increased for all five modeled species compared to the current condition. For example, under this combination, spring-run Chinook salmon habitat potential increased 13-fold and 10-fold under current (Figure 23) and future (Figure 24) climate conditions, respectively.

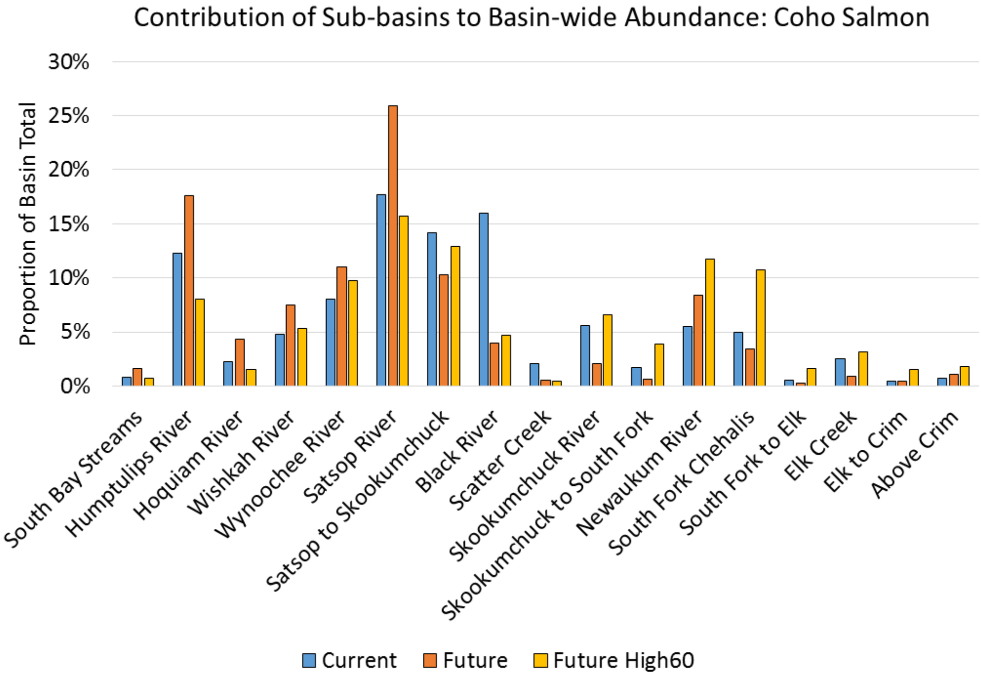
5 CONCLUSIONS

This analysis illustrated the interplay between geographic scale, habitat conditions, climate, and species life history and the interactions that affect conclusions regarding the effect of proposed flood damage reduction alternatives, habitat restoration, and climate change. The effect of the FRFA and FRO facilities on habitat potential for the five modeled species was found to be a function of 1) the scale of consideration, 2) the biological value of the habitat affected by the facilities under either alternative, and 3) assumed climate conditions.

At the basin-scale, the FRFA and FRO facilities had a small negative effect on habitat potential for the modeled species under current habitat conditions. However, at a local sub-basin scale (e.g., above Crim Creek) the dam options had substantial negative effects on the modeled species and greatly reduced or eliminated salmonid habitat potential in the upper Chehalis River. This could reduce spatial structure and biological diversity of populations and overall resilience of the species in the Chehalis Basin.

The biological value of the affected habitat under current, restored, or future climate conditions was found to have an important impact on the effect of the facilities on the modeled species across all scales. Current habitat above Crim Creek is degraded because of commercial logging; as a result, further degradation of that habitat due to the FRFA and FRO facilities had a small impact on Basin-wide habitat potential (Figure 10). However, if habitat value in the area affected by the facilities increased due to maturation of riparian areas in managed forests as assumed for ASHA, then the negative effect of the FRFA and FRO facilities increased substantially compared to their impact under current habitat conditions (Figure 19). Likewise, if current habitat potential in the area affected by the facilities was decreased as a result of future climate conditions, the negative effect of the facilities at the basin-scale decreased. These points are illustrated in Figure 25, which shows the proportional contribution of each sub-basin to the Basin-wide coho salmon habitat potential. Under future climate, coho salmon habitat potential was shifted downstream, increasing the contribution of the Satsop, Wynoochee, Wishkah, Hoquiam, and Humptulips rivers to the Basin-wide total habitat potential and decreasing the contribution from the upper Basin. Habitat potential above the dam site was reduced by future climate conditions, therefore the negative effect of the FRFA and FRO facilities under future climate conditions was slightly less than under current conditions. Adding the High60 restoration with future climate had the opposite effect: production was shifted upstream compared to the current condition and the Newaukum River, South Fork Chehalis River, Elk Creek, Elk to Crim, and above Crim Creek areas contributed a greater proportion of the Basin-wide coho salmon habitat potential than under the current habitat condition. When the FRFA or FRO facility options were included in this scenario, the negative impact of the facilities increased compared to current conditions. The upper sub-basins have a greater proportion of managed forest area and therefore disproportionately benefit from the restoration scenarios and the assumed passive restoration of riparian areas within managed forests.

Figure 25
Proportional Contribution of Individual Sub-basins to Basin-wide Coho Salmon Habitat Potential



One clear result of the analysis is the overwhelming impact of predicted future climate change on potential fish production in the Chehalis Basin. Further, this analysis only examined the effect of a change in climate on habitat within the Chehalis River and associated tributaries and assumed current conditions in Grays Harbor and the ocean. Climate change is likely to also affect conditions in Grays Harbor and the ocean and that could exacerbate the negative changes predicted in this analysis; therefore these results likely present a minimum estimate of the total effect of climate change. Under future climate conditions, habitat potential for spring-run Chinook salmon was reduced to the point that the persistence of spring-run Chinook salmon in the Chehalis Basin is questionable without significant habitat improvements to address issues such as high summer water temperature. Without habitat restoration, the abundance of fall-run Chinook salmon, coho salmon, and steelhead significantly declined under future climate conditions, which would have important implications for fisheries and harvest management. The analysis has indicated that habitat restoration has the potential to mitigate for the effect of future climate conditions and improve habitat potential for the five modeled species evaluated relative to current conditions. However, to create positive change in the Chehalis Basin, habitat restoration needed to address conditions throughout the Chehalis Basin and be effective in improving habitat conditions experienced by the modeled species. This will require a thoughtful, strategic approach to Basin-wide habitat restoration guided by the best available science.

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Appendix A
Documentation for the 2016 Chehalis Basin Ecosystem Diagnosis and Treatment Model and Current Baseline

The 2016 Chehalis Basin Ecosystem Diagnosis and Treatment (EDT) Model used to support the Programmatic Environmental Impact Statement (PEIS) is an application of the generalized EDT process (Mobrand et al. 1997) . The Chehalis EDT model encompasses the entire Grays Harbor watershed including the Chehalis River and other major tributaries entering Grays Harbor. The model was used to evaluate the effects of flood damage reduction actions and the potential value of habitat restoration actions for five anadromous salmonids. This appendix provides documentation for the EDT model in general and the Chehalis EDT model in particular.

1 DEVELOPMENT OF THE CHEHALIS EDT MODEL

The Chehalis River version of the EDT model was developed over the last 13 years in close collaboration with the Washington Department of Fish and Wildlife (WDFW), the Quinault Indian Nation, and other agencies and stakeholders. An EDT model was first developed for the Chehalis Basin in 2003 for the Chehalis Basin Task Force and WDFW (Mobrand Biometrics 2003). Subsequent versions in 2014 (Anchor QEA 2014) and 2016 (the current version) have been developed to support the Chehalis Basin Strategy. The evolution of the model reflects improvements in knowledge and data and an evolving understanding of conditions in the Basin and the effects of future climate.

The 2014 EDT model imported information from the 2003 model into the current software platform (EDT3, Box 1) and updated the model with new data from WDFW and other parties. The 2014 model evaluated flood damage reduction alternatives and habitat restoration strategies, including a set of generalized assumptions regarding future climate conditions (Anchor QEA 2014).

The 2016 Chehalis EDT model added further refinements including linkages to flow and temperature models and to GIS tools. In addition, web mapping tools were developed to display model structure, data inputs, and model results more effectively. The analysis of climate change was refined with input from the University of Washington Climate Impacts Group (Mauger et al. 2016).

Box 1: Versioning in EDT

EDT has been used for fishery planning in the Pacific Northwest for over two decades. There have been three recognized benchmarks for the model: EDT1, EDT2, and EDT3. EDT2 moved the model from a Microsoft Access application to the web so that it could be accessed by users across the region. EDT2 was used in the regional Sub-basin Planning Process organized by the Northwest Power and Conservation Council in 2004; the original Chehalis EDT model was developed using EDT2 in 2004. The Chehalis EDT model developed for the Chehalis Basin Strategy was constructed using the current EDT3 platform. EDT3 is a significant upgrade made in 2015 to incorporate current software standards and many additional features. EDT3 is the currently supported version of the model.

2 ECOSYSTEM DIAGNOSIS & TREATMENT

2.1 Background and Theory

EDT is a systematic approach to the restoration of aquatic habitat and the evaluation of stream habitat with respect to potential performance of salmonid fishes. The model has been used to evaluate aquatic habitat for salmonids in the Pacific Northwest since the 1990s. It is the basis of many watershed plans and Endangered Species Act species recovery plans in the Columbia Basin and Puget Sound. The original concepts and theoretical basis for the EDT process are described in Lichatowich et al. (1995) and Mobrand et al. (1997). Algorithms, assumptions, and mechanisms of the EDT model are detailed in Blair et al. (2009). Guidelines for rating attributes in EDT are described in Lestelle (2004).

EDT is a life-cycle model based on the mathematics of the Beverton-Holt stock-recruitment relationship (Hilborn and Walters 1992). The EDT life-cycle model uses the disaggregated form of the Beverton-Holt function (Moussalli and Hilborn 1986) to integrate life stage performance of the modeled species across multiple life-history trajectories. These trajectories are spatiotemporal pathways defined by the species life history. The model typically generates thousands of trajectories defined by windows of time and location of life stages. The performance of fish along each trajectory is computed using the disaggregated Beverton-Holt function and then integrated to estimate population-level performance with variation.

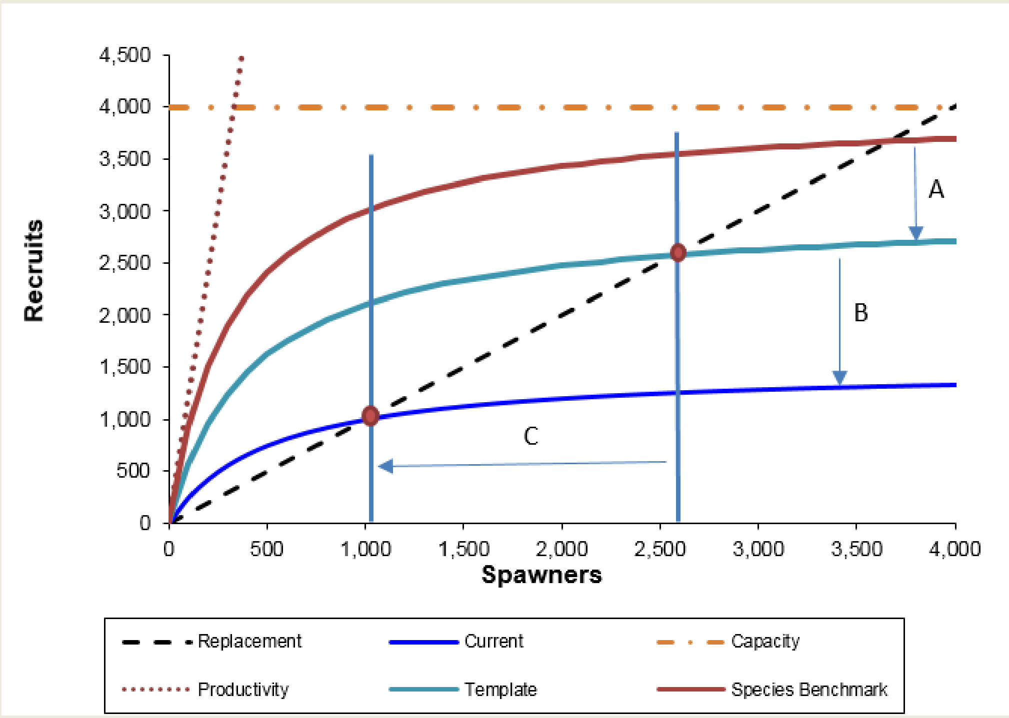
The Beverton-Holt function is defined by two parameters (Box 2): density independent survival or Productivity and the Carrying Capacity of the environment. Density-dependent factors in a population reduce density-independent survival such that the population abundance will approach the asymptotic Carrying Capacity (Box 2). Productivity and capacity are computed in EDT for each trajectory based on the quantity and quality of habitat encountered by life stages across the species life history. These parameters are computed in EDT from reach-level habitat data using a knowledge base of heuristic species habitat relationships.

A fundamental concept of EDT is that fish within a population exhibit a range of life-history strategies (sensu Stearns 1992) that reflect the underlying spatial and temporal heterogeneity in conditions encountered across the life history (Lichatowich et al. 1995). Performance of fish along these pathways (measured by productivity and capacity) reflects the conditions encountered and the duration of exposure of the life stages to those conditions. As a result, population performance is not a single measure of productivity and capacity, but rather the integration of performance across the diversity of life histories that could be expressed across the environmental mosaic. The EDT life-cycle model typically generates thousands of life-history trajectories that are defined by life-stage timing and location windows. The model evaluates the performance of these trajectories against environmental conditions in the modeled system, generating a range of possible biological performance that reflects environmental heterogeneity and biological response.

Box 2: Evaluating Habitat Using Stock Recruitment Relationships

EDT is based on the mathematics of the Beverton-Holt (B-H) stock-recruitment function (Hilborn and Walters 1992). The population-level B-H relationship is disaggregated in the model to compute life stage abundance and integrated across the life history trajectories to compute population performance (Moussalli and Hilborn 1986). As illustrated in the example below, the stock-recruitment function relates the number of Spawners and their progeny or Recruits. The abundance of Recruits is a function of the number of Spawners, the density independent survival (productivity), and the asymptotic carrying capacity. The replacement line (the dashed line where Recruits = Spawners) crosses the calculated abundance at the point of Equilibrium Abundance (red dots). Productivity (Recruits/Spawner) and capacity (numbers of fish) are related to the quality and quantity of habitat respectively. In EDT, the B-H parameters are computed by adjusting a set of species/life stage specific benchmark survival and density values to reflect conditions in the modeled watershed using a large library of heuristic species-life stage habitat relationships.

The illustration below begins with a hypothetical B-H curve using the benchmark survival and density value (red line). This relationship is adjusted to reflect specific habitat conditions in a watershed in the Template (green line) and Current (blue line) scenarios. The Template scenario captures the intrinsic condition of the watershed without anthropogenic impacts. The Current scenario captures the current condition of the watershed with anthropogenic impacts. Arrow A shows the reduction from species benchmark performance to reflect the intrinsic features of the Template condition. Arrow B shows further reduction in performance under the Patient or current condition constrained by anthropogenic factors. Arrow C shows the resulting change in equilibrium abundance predicted for the watershed due to anthropogenic degradation of the habitat.



Typically, the performance of the trajectories is integrated into population-level parameters while preserving the underlying variation in modeled performance. The integration of life-history performance produces population metrics consistent with the Viable Salmonid Population (VSP) concept (McElhany et al. 2000) developed by NOAA to provide metrics for setting objectives for recovery of ESA listed salmonid populations. The VSP performance metrics as used within EDT are defined as follows.

- Productivity: density-independent survival based on habitat quality
- Abundance: number of adult spawners at the Beverton-Holt equilibrium (Box 2)
- Biological Diversity: variation in life-history expression based on habitat heterogeneity
- Spatial Structure: variation in population performance between populations across a landscape (e.g., the Chehalis Basin)

Abundance is calculated as the equilibrium point from the Beverton-Holt equation and combines the effect of quality and quantity of habitat. Because EDT evaluates habitat potential across numerous life-history trajectories the relative success of these trajectories provides insights into the potential biological and life-history diversity of the target fish population. Evaluating habitat across a complex riverscape such as the Chehalis Basin describes the spatial structure of the species within the defined environment.

The productivity and capacity values used in the EDT life-cycle model are calculated by downgrading a set of species and life-stage-specific productivity and density (fish per square meter) benchmarks to reflect specific conditions in a watershed, reach, and month (Box 2). Typically, two scenarios are initially created: a Template scenario that captures historic conditions in the watershed and serves as a reference condition of the watershed without anthropogenic constraints (Poff and Ward 1990) and a Current scenario that captures the current condition of the watershed (usually degraded by human activity; Lichatowich et al. 1995). The species/life stage habitat relationships in EDT adjust the benchmarks based on modeled and empirical data on conditions in the modeled watershed (Box 2). The species benchmark productivity and density are reduced by the intrinsic conditions of the watershed, including geology, climate, and landcover, to create the Template condition (Box 2, Arrow A). Fish performance under Current conditions is further reduced by anthropogenic factors (Box 2, Arrow B). The space in between the Template and Current lines on the figure in Box 2 is a measure of the effect of anthropogenic factors on fish performance in the watershed. This results in a reduction in estimated abundance potential of the species in the modeled watershed (Box 2, Arrow C).

2.2 EDT Input Data

The EDT model is structured around a spatial network of reaches that proscribe the study area. Reaches are defined by geomorphic characteristics and by obstructions such as culverts or waterfalls. Obstructions are treated as reaches of zero length, but with a monthly pattern of upstream and downstream survival by species and life stage. Non-obstruction reaches are described by environmental attributes (Table A-1). The environmental attributes are shaped by month within a year for a “typical” condition that defines a scenario (e.g., the current condition) using a variety of data sources including observations and measurements, results from a physical model (e.g., HEC-RAS), and the knowledge of local and regional experts. Data for many of the environmental attributes are standardized and input into EDT using a set of categorical ratings (Box 3; Lestelle 2004). Other attributes use direct measurement data (length and width of reaches) as well as the proportional distribution of habitat types within a reach. Habitat types in EDT are based on the scheme of Hawkins et al. (1993) shown in Figure A-1.

Box 3: Categorical Ratings in EDT

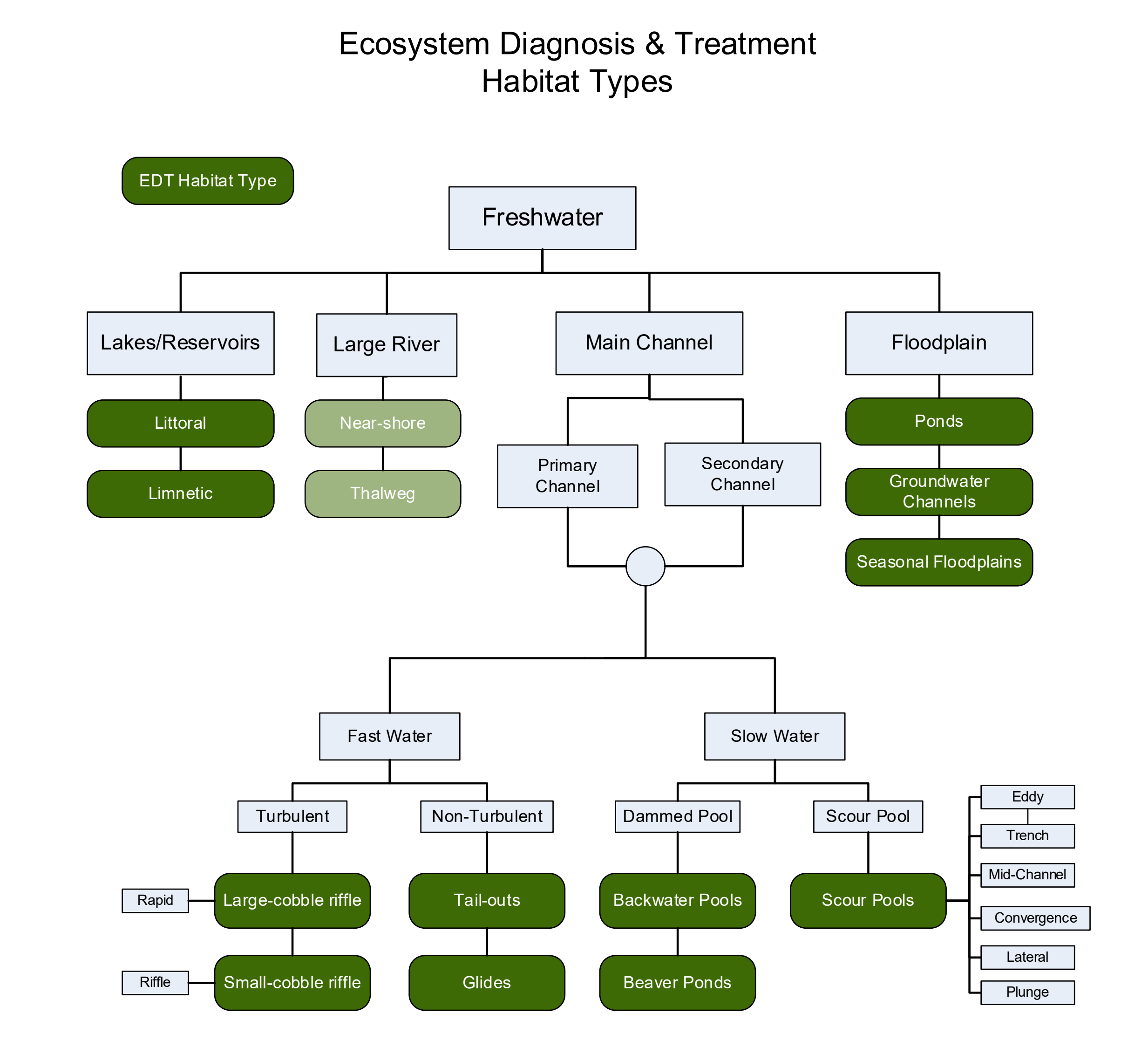
The heuristic species-habitat relationships in EDT downgrade a set of benchmark survival and density measures to reflect reach-level conditions the modeled stream. The data for most of the environmental attributes is input as categorical values from 0 to 4 that are tied to the shape of the species-habitat relationships and concise definitions (Lestelle 2004). For most attributes, a 0 represents no degradation of the benchmark condition as a result of the attributes (therefore very good condition) and a 4 represents an extreme decrease in benchmark survival due to the attribute.

Table A-1
EDT Environmental Attributes Used to Compute the Habitat Capacity and Productivity Factors (Table A-2).

CATEGORY	ATTRIBUTE	DATA TYPE
Flow	Change in high flow	Categorical
	Change in low flow	Categorical
	Diel flow variation	Categorical
	Intra-annual flow variation	Categorical
	Water withdrawals (entrainment)	Categorical
	Natural hydrologic regime	Categorical
	Regulated hydrologic regime	Categorical
Channel Form	Natural channel confinement	Categorical
	Modified channel confinement	Categorical
	Obstructions	Passage efficiency (% survival)
	Bed scour	Categorical
	Riparian function	Categorical
	Large wood	Categorical
Sediment	Embeddedness	Categorical
	Fine sediment (intra-gravel)	Categorical
	Turbidity	Categorical
Water Quality	Alkalinity	Categorical
	Dissolved oxygen	Categorical
	Metals in water	Categorical
	Metals in sediment	Categorical
	Other toxins in water	Categorical

CATEGORY	ATTRIBUTE	DATA TYPE
	Nutrient enrichment	Categorical
Temperature	Annual maximum temperature	Categorical
	Annual minimum temperature	Categorical
	Spatial variation in temperature	Categorical
Biological Community	Fish community richness	Categorical
	Pathogens	Categorical
	Fish species introductions	Categorical
	Harassment	Categorical
	Hatchery outplants	Categorical
	Predation risk	Categorical
	Salmonid carcasses	Categorical
	Benthos diversity and production	Categorical
Morphometry (capacity)	Habitat type—Backwater pools	% reach area
	Habitat type—Beaver ponds	% reach area
	Habitat type—Glides	% reach area
	Habitat type—Large cobble riffles	% reach area
	Habitat type—Small cobble riffles	% reach area
	Habitat type—Tailouts	% reach area
	Habitat type—Primary pools	% reach area
	Habitat-type—off channel	% reach area
	Channel length	Length (kilometers)
	Maximum Channel width	width (meters)
	Minimum Channel width	width (meters)
	Gradient	% rise over reach

Figure A-1
Stream Unit Habitat Used in the EDT Model



2.3 Limiting Factors in EDT

The VSP population metrics used in EDT to characterize potential fish performance are computed by adjusting the life-stage-specific survival and density benchmarks to reflect actual conditions in the modeled environment by reach and by month across a year. This is done using a set of heuristic relationships between habitat conditions and survival (productivity) and fish density (capacity) that adjust life stage benchmark values for productivity and density. Benchmarks are the maximum survival and density under ideal conditions and bound model performance. The heuristic relationships combine one or more environmental attributes (Table A-1) to define productivity factors and capacity factors (Table A-2).

The equation below shows the computation of the life stage survival (P_s) as a function of Productivity Factors (F_n) that adjust the life stage benchmark productivity (P_0) to reflect the actual conditions in a stream.

$$P_s = P_0 \cdot F_1 \cdot F_2 \cdot F_3 \cdots F_{16}$$

A similar process involving Capacity Factors is used to adjust life stage density (fish per square meter) to reflect habitat quality and compute habitat capacity. The productivity and capacity factors in EDT are presented as habitat-limiting factors that describe how the environment in a specific stream in a specific scenario modifies and constrains productivity and capacity (Table A-2).

Table A-2
Habitat Capacity and Productivity Factors in EDT (Habitat Limiting Factors)

FACTORS	DEFINITION
HABITAT CAPACITY FACTORS	
Channel Length	The thalweg length of a reach in kilometers. Length can change due to channel straightening or re-meandering
Width	The average monthly wetted width of the channel in meters. Usually something less than bank full width that reflects episodic flood events. Width changes due to channelization, rip-rap, or other constraints on channel form.
Habitat Composition	The percent of surface area of a reach (length X width) by primary channel form type (e.g., pools and riffles). EDT uses a habitat classification scheme based on Hawkins et al. (1993) and includes main channel, floodplain, and side channel habitat types.
Food	Food affects both capacity and productivity. The effect of the amount, diversity, and availability of food that can support the focus species on its relative survival, capacity, or performance. Food reflects overall stream productivity (indexed by alkalinity), riparian condition, as well as benthic community and salmon carcasses.
HABITAT PRODUCTIVITY FACTORS	
Channel Stability	The condition of the channel with respect to normative channel dynamics. It is defined as a function of bed scour, riparian function, and woody debris.
Chemicals (Pollutants)	The effect of toxic substances or toxic conditions on the relative survival or performance of the focus species. Substances include chemicals and heavy metals. Toxic conditions include low pH.
Competition with Hatchery Fish	The effect of competition with hatchery produced animals on the relative survival or performance of the focus species; competition might be for food or space within the stream reach. This competition factor is a function of hatchery fish outplants, riparian condition, and benthic community.
Competition with Other Species	The effect of competition with other species on the relative survival or performance of the focus species; competition might be for food or space. This competition factor is a function of introduced species, benthic invertebrates, riparian condition, and alkalinity.

FACTORS	DEFINITION
Flow	The change in magnitude, pattern, or schedule of flow relative to the historic normative condition. EDT measures this in terms of the change in average peak flow, average base flow, inter-annual flow, and intra-annual flow (flashiness). Note that the flow attribute in EDT does not include the effect of flow on other key stream attributes such as channel width. These effects are reflected in the ratings for the individual attributes (e.g., width, sediment movement, temperature, channel stability).
Habitat Diversity	The physical and hydrologic complexity of habitat in a reach. Greater diversity of habitats provides refugia and key habitat for life stages. In EDT Habitat Diversity is defined as a function of gradient, riparian condition, woody debris, and channel confinement.
Oxygen	The effect of the concentration of dissolved oxygen within the stream reach on the relative survival or performance of the focus species.
Pathogens	The effect of pathogens within the stream reach on the relative survival or performance of the focus species. Pathogen effects increase in EDT due to known presence of pathogens, the amount of fish species introductions, and especially temperature.
Predation (Predator Concentrations)	The effect of an increase in predation over the normative condition. We assume predation to be a fact of life for salmonids. This factor addresses the effect of dams, outfalls, and the introduction of non-native predators that increase the effect of predation relative to the normative condition.
Sediment	The effect of the amount of fine sediment present in, or passing through, the stream reach on the relative survival or performance of the focus species. Sediment load in EDT is a function of turbidity (suspended solids) and maximum temperature.
Temperature	The effect of water temperature within the stream reach on the relative survival or performance of the focus species. Temperature in EDT can be affected by maximum temperature across a month, minimum monthly temperature, temperature pattern, and spatial variation (temperature refugia). These attributes capture the temperature experienced by fish in a month and are based on days of exposure of life stages to critical temperatures as defined by the Environmental Protection Agency.
Withdrawals (Impingement)	The effect of entrainment (or injury by screens) at water withdrawal structures within the stream reach on the relative survival or performance of the focus species. This effect does not include dewatering due to water withdrawals, which is covered by the flow attribute.
Food	Food affects both capacity and productivity. The effect of the amount, diversity, and availability of food that can support the focus species on its relative survival, capacity, or performance. Food reflects overall stream productivity (indexed by alkalinity), riparian condition, as well as benthic community and salmon carcasses.

3 COMPONENT MODELS OF THE 2016 CHEHALIS EDT MODEL

The measures encompassed by the Chehalis Basin Strategy were evaluated in the PEIS using a suite of physical and biological models and information sources. The physical models were the basis for parameterizing key attributes in the Chehalis EDT model (e.g., flow and temperature). Figure A-2 shows the models and information sources used to create the 2016 Chehalis EDT model and to evaluate the flood damage reduction measures and the Aquatic Species Habitat Actions (ASHA) habitat restoration on the future abundance and persistence of the five modeled salmonid species.

Models shown in Figure A-2 are described as follows.

HEC-RAS. The Hydraulic Engineering Center-River Analysis System, HEC-RAS is a widely used hydraulic analysis tool developed by the U.S. Army Corps of Engineers.[1] Both 1-D and 2-D versions of the model were used in this analysis to compute flow and channel width in the mainstem Chehalis River under current and alternative future conditions and to compute the extent of floodplain inundation along the mainstem river as a function of flow. HEC-RAS modeling was conducted by Anchor QEA (Adam Hill) and by Watershed Science and Engineering (Larry Karpack).

CE-QUAL-W2. Water temperature along the mainstem Chehalis River was modeled by Portland State University (PSU; Van Glubt et al. 2016) using the CE-QUAL-W2 model.[2] CE-QUAL-W2 is a 2-D (longitudinal/vertical) model of water dynamics and quality that has been widely used to model temperature, dissolved oxygen, pH, and other water quality parameters. For the EDT analysis, the PSU model provided detailed temperature information at numerous model segments along the mainstem Chehalis from the proposed dam site (River Mile 108) down to Porter (River Mile 33.3) based on water years 2013 and 2014. A separate model was developed to estimate temperature effects in the Chehalis River reaches that would be encompassed by the project reservoir behind the proposed Flood Retention Only (FRO) facility; the reservoir footprint model took into account shading under current and proposed facility conditions.

In addition to the PSU model, Anchor QEA developed a CE-QUAL-W2 model that was used to estimate temperature in the reservoir behind the proposed Flood Reduction/Flow Augmentation (FRFA) facility.

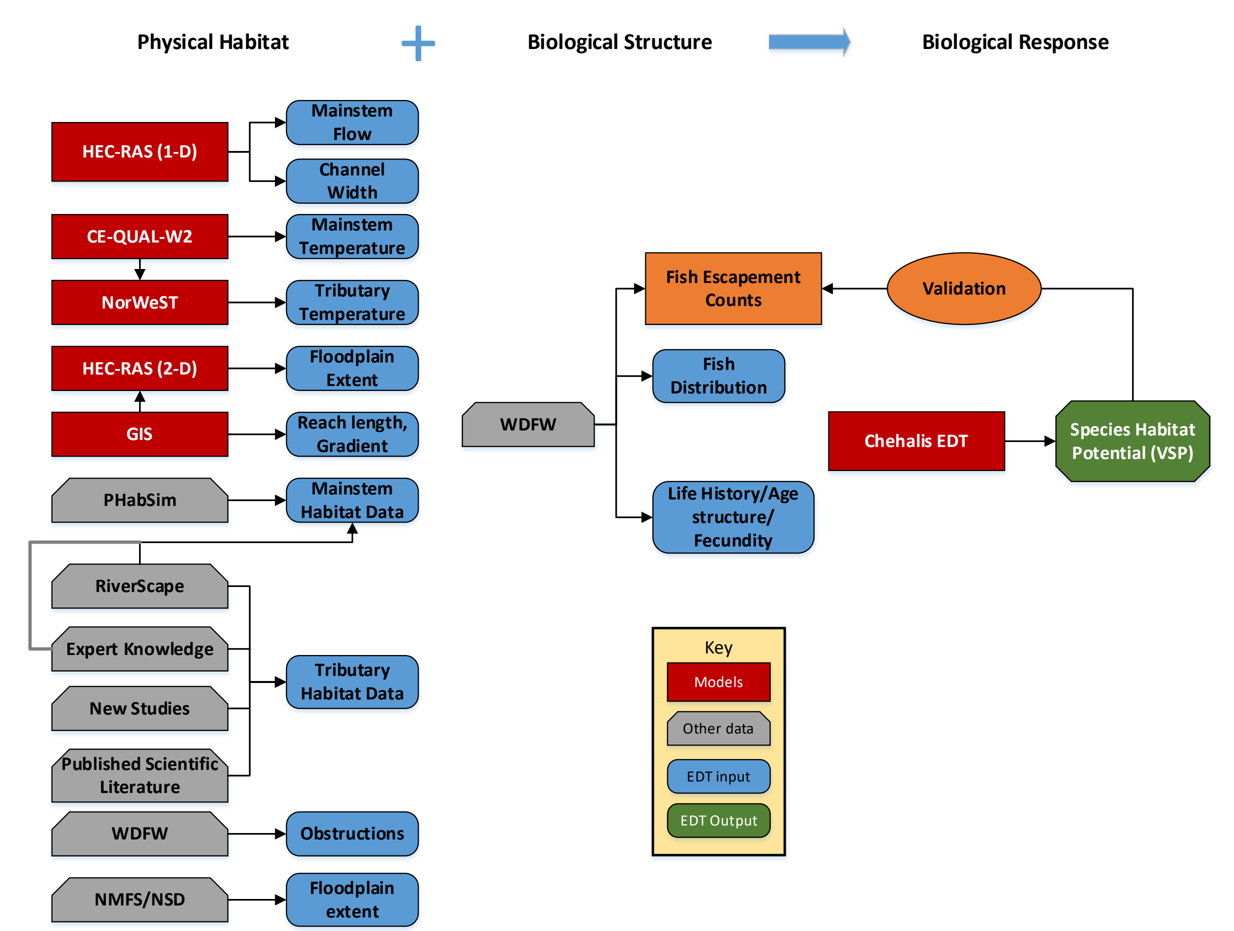
NorWeST. The PSU model estimated temperature in the mainstem Chehalis River and did not extend into the tributaries. Estimation of temperature in the tributaries relied on the NorWeST model developed by U.S. Forest Service Rocky Mountain Research Center.[3] The NorWeST system provides

[1] http://www.hec.usace.army.mil/software/hec-ras/documentation.aspx
[2] http://www.cee.pdx.edu/w2/
[3] https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

estimates of average August water temperature in streams across the western United States, including the Chehalis Basin. As will be discussed in Section 4.2.6, the NorWeST data was used in conjunction with the PSU temperature model to estimate tributary water temperatures throughout the Chehalis Basin.

Ecosystem Diagnosis & Treatment. Effects of environmental conditions characterized by the models and sources in Figure A-2 were evaluated using EDT (Mobrand et al. 1997). Most of this documentation focuses on the development of the Chehalis EDT model.[4]

Figure A-2
Models and Information Used to Construct the 2016 Chehalis EDT Model



[4] http://ecosystems.azurewebsites.net/Chehalis_River/

4 THE 2016 CHEHALIS EDT MODEL AND CURRENT CONDITIONS

The Chehalis EDT model is an application of the general EDT model incorporating habitat and biological data specific to the Chehalis River. Habitat potential of the five modeled species under current conditions was used as the baseline for comparison of the effects of the modeled actions.

4.1 Geographic Organization

The spatial scope and network of the 2016 Chehalis EDT model is shown in Figure A-3. The Chehalis EDT stream network is based on the 1:24,000 National Hydrography Dataset (NHD) hydrography developed by the U.S. Geological Survey.[5] The NHD hydrography was intersected with the fish distribution data using the Washington State-Wide Integrated Fish Distribution (SWIFD) data. The SWIFD fish distribution did not include all the small tributaries in the NHD hydrography or streams that were judged by WDFW not to support the five target salmonid species, even if they support other species such as Cutthroat trout.[6] Hence, the EDT hydrography is a reduction in the 1:24,000 NHD coverage to reflect known fish distribution. The resulting model network includes 2,638 total reaches (including obstructions) encompassing 2,170 total stream miles (Figure A-4). Reaches are delineated based on geomorphology as well as physical features such as obstructions (e.g., culverts). Reach lengths and gradients were derived through GIS analysis of maps and aerial photographs. The 2,638 reaches were organized based on hydrology as follows.

Chehalis Basin and Grays Harbor Tributaries (All major streams entering Grays Harbor)

↓

32 Sub-basins (e.g., Newaukum River)

↓

111 Diagnostic Units (e.g., South Fork of the Newaukum River)

↓

2,638 Stream Reaches

One or more stream reaches constitute a diagnostic unit, one or more of which constitute a sub-basin, which collectively describe the Chehalis Basin and Grays Harbor tributaries. Stream reaches are the smallest hydrological unit in the model and all data are entered at that scale and shaped across months in a year. Reaches were aggregated into diagnostic units, which were the smallest spatial unit of EDT results used in the PEIS.

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[5] https://nhd.usgs.gov/

[6] The SWIFD data in the Chehalis Basin is under review by WDFW and the tribes and is likely to be expanded in the coming months.

Figure A-3
Spatial Extent and Hydrologic Network of the Chehalis EDT Model (Divided into 32 Sub-Watersheds)

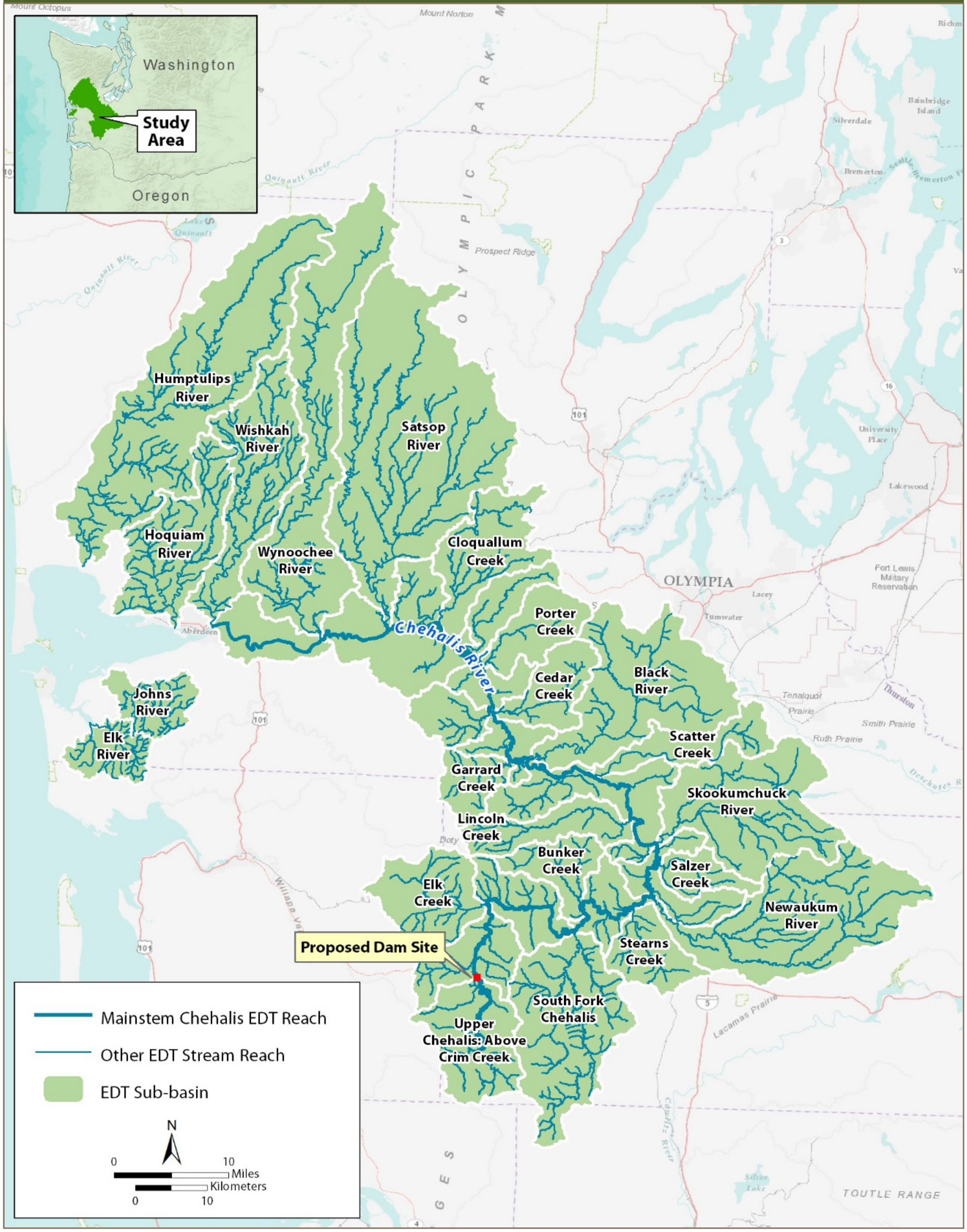


Figure A-4
Geographic Organization of the Chehalis EDT Model

Sub-basin	Diagnostic Units	Reaches	Length (km)
Satsop River	16	201	356.5
Humptulips River	10	286	344.5
Newaukum River	9	137	243.4
South Fork Chehalis	7	163	228.8
Wishkah River	4	176	228.3
Wynoochee River	7	131	223.6
Hoquiam River	8	179	205.8
Black River	6	101	153.6
Skookumchuck River	3	87	151.7
Chehalis Black to Skook	3	103	100.3
Johns River	1	128	93
Chehalis above Crim	7	42	91.2
Cloquallum Creek	1	65	90.4
Elk Creek	1	35	88.7
Chehalis Satsop to Porter	4	71	87
Elk River	2	98	84.7
Chehalis Elk to Crim	3	55	74.3
Chehalis South Fork to Elk	2	58	68.4
Lincoln Creek	1	44	66.5
Chehalis Skook to Newaukum	2	47	50.4
Bunker Creek	1	53	50.3
Stearns Creek	1	78	50.1
Garrard Creek	1	41	50
Chehalis Newaukum to SF	2	84	48.2
Chehalis Porter to Black	2	27	44.1
Scatter Creek	1	21	44
Cedar Creek	1	37	41.1
Mox Chehalis Creek	1	18	34.1
Chehalis Estuary	2	19	33.3
Rock Creek (Lower Chehalis)	1	17	32.4
Salzer Creek	1	25	28.2
Porter Creek	1	11	23.3
32	111	2,638	

4.2 Biological Organization

Habitat potential of the Chehalis Watershed was evaluated with regard to five species of anadromous salmonids (for modeling purposes the two runs of Chinook salmon are treated as separate species).

- Chinook salmon
  - Fall-run
  - Spring-run
- Coho salmon
- Chum salmon
- Winter steelhead

4.2.1 Population Structure

Species life-history trajectories are aggregated to form "populations" for EDT purposes (Table A-3). EDT populations are aggregations of life-history trajectories based on habitat and do not imply genetic structure. The Chehalis EDT populations encompass multiple diagnostic units (Figure A-4) that reflect the migratory life history of anadromous salmonids. For example, habitat potential for the EDT Newaukum coho salmon population reflects the performance of all life-history trajectories starting from reaches within the sub-basin and extending downstream to the estuary. Habitat potential of coho salmon spawning in the Newaukum River reflects conditions in the nine diagnostic units in the Newaukum sub-basin (e.g., South Fork, Middle Fork, North Fork) as well as four additional diagnostic units in the mainstem Chehalis River downstream of the Newaukum. Collectively, these 13 diagnostic units encompass the habitat in the Chehalis River experienced by coho salmon spawning in the Newaukum sub-basin.

Table A-3
Salmonid Population Structure in the Chehalis EDT Model

SUB-BASIN	CHUM	FALL-RUN CHINOOK	SPRING-RUN SHINOOK	STEELHEAD	COHO
Above Crim Creek		■	■	■	■
Black River	■	■		■	■
Elk Creek		■	■	■	■
Elk to Crim Creek		■	■	■	■
Hoquiam River	■	■		■	■
Humptulips River	■	■		■	■
Newaukum River	■	■	■	■	■
Satsop River	■	■		■	■
Satsop to Skookumchuck	■	■	■	■	■
Scatter Creek	■				■
Skookumchuck River	■	■	■	■	■
Skookumchuck to South Fork	■	■	■	■	■
South Bay Streams	■	■		■	■
South Fork Chehalis	■	■	■	■	■
South Fork to Elk	■	■	■	■	■
Wishkah River	■	■		■	■
Wynoochee River	■	■		■	■

4.2.2 Species Life Histories

Salmonids have evolved a diverse array of life histories to meet the challenges imposed by the environment (Healey and Prince 1995). The pattern of movement, distribution, and timing of salmonids across the landscape is an important determinant of the impacts of environmental conditions including the type of actions evaluated in this analysis. The EDT life-cycle model is based on the life history of the modeled species in the Chehalis Basin. The model has considerable flexibility in designing salmonid life histories, allowing multiple life-history configurations to be tested against environmental conditions. Typically, there is considerable variation in the success between life histories in EDT; this creates a hypothesis about how the environment might select between life-history strategies based on the underlying habitat condition. EDT samples the environment by creating life-history trajectories (Mobrand et al. 1997). These are spatial and temporal pathways across the watershed, estuary, and ocean that begin and end with spawning at a particular location and month. These trajectories determine where, when, and for how long life stages are exposed to reach-level habitat conditions. EDT creates several thousand trajectories by stochastically sampling within a defined spatial and temporal window that proscribes the possibilities for life stages. The life-history patterns determine where and for how long fish in each life stage occupy specific habitats, allowing the model to apply the appropriate habitat rating functions and determine the duration of exposure of the life stage to physical conditions in specific (occupied) reaches. Each species has unique spawning distribution, rearing reaches, and life-history timing that are incorporated in their various life-history patterns.

Life history patterns of Chehalis salmonids have been described in Washington Department of Fisheries (1975) and Smith and Wenger (2001). These descriptions were used along with consultation with WDFW biologists to develop the following life patterns for the five species that were used in the model.

Spring-run Chinook Salmon: Spring-run Chinook salmon in the Chehalis River predominantly follow an ocean-type life history (Smith and Wenger 2001). In the model, spring-run Chinook salmon adults were assumed to enter the Chehalis River in late winter, spring, and early summer and move upstream to holding areas near eventual spawning habitat (Figure A-5). Adults were assumed to hold in the river from spring-run to early fall-run when spawning occurs. Juveniles emerged in the following spring-run, distributed downstream, and emigrated in their first spring. A small proportion were assumed to delay emigration until the following spring to emigrate as yearlings. Adults spent 2 to 5 years in the ocean. Juvenile life-history patterns for spring-run Chinook salmon are described below along with their allocation across the modeled life-history trajectories.

- Fry Migrant (45%): Rapid downstream migrant about 3 weeks after emergence. Extended residence in the estuary.
- Fingerling Migrant (45%): Conventional ocean-type Chinook salmon. Soon after emergence they begin moving downstream slowly, eventually increasing speed to enter the estuary in late spring-run.
- Yearling Migrant (10%): Stream type. Spends winter in or near natal reach, smolts the following spring-run; moves downstream rapidly to estuary.

Fall-run Chinook Salmon: Fall-run Chinook salmon in the Chehalis Basin primarily follow an ocean-type life history (Smith and Wenger 2001). In the model, fall-run Chinook salmon adults were assumed to enter the Chehalis River in fall and move upstream to spawning habitat with a relatively short adult pre-spawning holding period compared to spring-run Chinook salmon (Figure A-5). Juveniles emerged in the following spring, distributed downstream, and emigrated in their first spring. A small proportion were assumed to delay emigration until the following spring-run to emigrate as yearlings. Adults spent 2 to 5 years in the ocean. Juvenile life-history patterns for fall-run Chinook salmon are described below along with their allocation across the modeled life-history trajectories.

- Fry Migrant (45%): Rapid downstream migrant about 3 weeks after emergence. Extended residence in the estuary.
- Fingerling Migrant (45%): Conventional ocean-type Chinook salmon. Soon after emergence they begin moving downstream slowly, eventually increasing speed to enter the estuary in late spring.
- Yearling Migrant (10%): Stream type. Spends winter in or near natal reach, smolts the following spring; moves downstream rapidly to estuary.

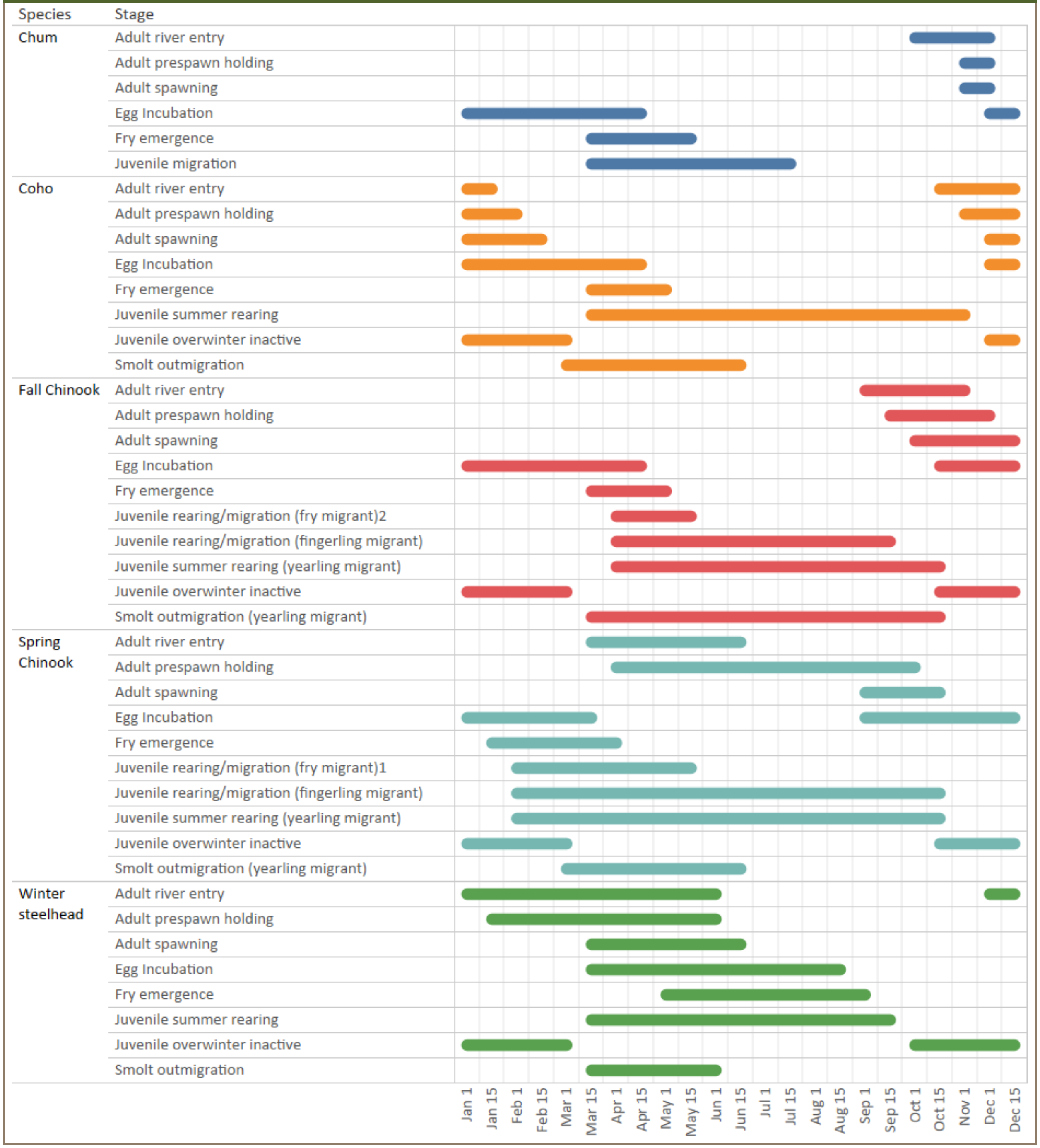
Coho Salmon: Coho salmon were assumed to follow a standard coho salmon stream-type life history (Smith and Wenger 2001). Adults were assumed to return to the Chehalis River in fall, migrate upstream and spawn in late fall/early winter. Juveniles emerge in the spring and spend the next year in various habitats within the Chehalis River basin (Figure A-5). A fall dispersal of juveniles downstream was assumed. Emigration from the system occurred in the second spring-run after 1 year in freshwater using the juvenile life-history patterns described below. Adults spend 2 years in the ocean; total age at spawning is 3 years. Juvenile life-history patterns for coho salmon are described along with their allocation across the modeled life-history trajectories.

- Resident (50%): Migrates no more than 40 kilometers downstream of natal reach during juvenile rearing, moves rapidly downstream in the second spring-run to the estuary.
- Migrant (50%): Extended downstream movement including fall-run redistribution downstream. Could migrate almost to the estuary during juvenile rearing, reaching the estuary in second spring-run.

Chum Salmon: Chum salmon spend the least amount of time in freshwater of the five modeled species. They were assumed to enter the river in fall (Figure A-5) and spawn in the lower sections of tributaries to Grays Harbor and the mainstem Chehalis up to about the South Fork Chehalis River. Juvenile chum salmon were assumed to move downstream and enter the estuary soon after emergence, spending their early rearing in the estuary. Juvenile life-history patterns for chum salmon are described along with their allocation across the modeled life-history trajectories.

- Fry Migrant (50%): Goes straight to the estuary during the 1 to 2 weeks after emergence.
- Transient Migrant (50%): Migrates downstream slowly, eventually increasing speed to enter estuary several weeks after emergence.

Figure A-5
Life Stage Periodicity Used in the Chehalis EDT for the Five Modeled Salmonid Species



Notes:
1. Fry migration to estuary
2. Fry migration to estuary

Steelhead: Winter steelhead spend the greatest amount of time in freshwater of the five modeled species. Adult steelhead were assumed to enter the Chehalis River in late fall-run and through the winter (Figure A-5). Spawning was in late winter and spring. Juveniles were assumed to spend 2 to 3 years in freshwater; most were assumed to spend 2 years in the Chehalis Basin. Assumed life-history patterns used in the model proportional distribution across the life-history trajectories.

- 85% spend 2 years in freshwater; 15% spend 3 years in freshwater.
- Resident (50%): Stays relatively close to natal reach before smolting.
- Transient (50%): Alternating periods of rearing and migration throughout the summer rearing period in all pre-smolting years.

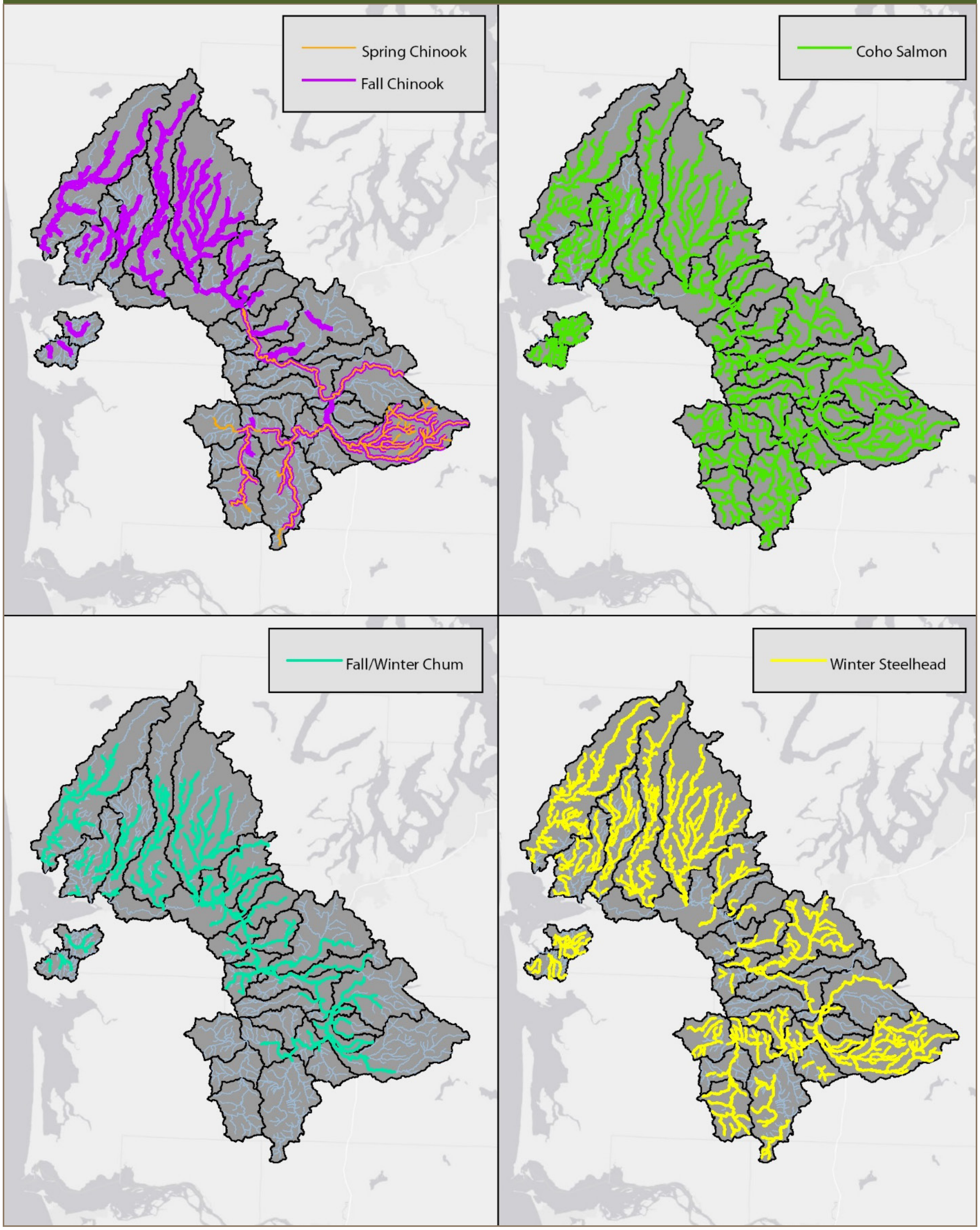
4.2.3 Spawning Distribution

The spawning distribution in EDT defines the range of each species within the modeled stream network. Spawning reaches in EDT are the starting and ending points for life-history trajectories. They are intended to encompass the potential distribution of the species and are more expansive than the currently observed locations of spawning activity. Potential distribution captures the fish distribution in the Basin that likely occurred historically prior to large-scale anthropogenic changes. This extends beyond the currently observed fish distribution (which may be limited by culverts or other conditions), but captures the historic spatial extent of the species in the watershed. In a few cases, the EDT distribution extended beyond the presumed historic distribution to include areas above historic barriers to fish passage that have been improved, laddered, or removed by fishery managers. Using the potential fish distribution allows the model to evaluate the impact of removing currently impassable barriers. The EDT model reduces the potential fish distribution to current conditions based on culvert passage and other EDT attributes. For example, a barrier with a 0% passage rating would prevent evaluation of habitat above the barrier under current conditions.

The assumed spawning distribution was based on the 2003 EDT model (Mobrand Biometrics 2003), the WDFW SalmonScape data,[7] and advice from regional experts (Holt 2016; Zimmerman 2016). This complete distribution for each of the modeled species can be viewed on the EDT attribute mapping site[8] and in Figure A-6. Coho salmon have the most expansive distribution in the Basin and spring-run Chinook salmon the most restricted distribution.

[7] http://apps.wdfw.wa.gov/Salmonscape/
[8] http://ecosystems.azurewebsites.net/chehalis2016edt/

Figure A-6
Assumed Spawning Distribution for Chehalis Basin Salmonids



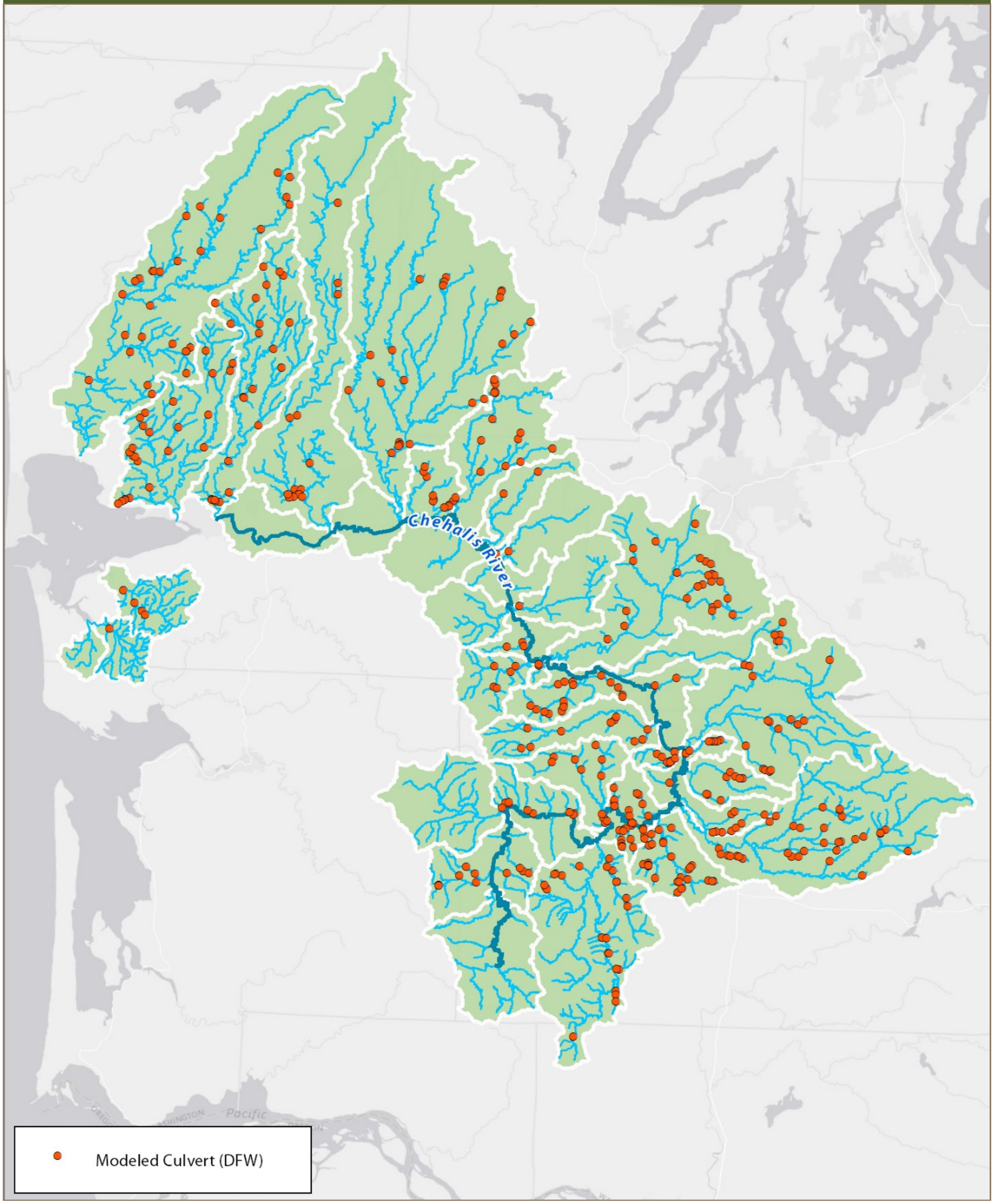
4.2.4 Obstructions

Obstructions are treated as distinct objects in the EDT stream network that are rated in regard to upstream and downstream passage effectiveness by species and life stage. Obstructions include both natural and artificial barriers (e.g., culverts) based on the 2003 EDT model updated with the 2015 inventory compiled by WDFW. Obstructions included in the model were those in the WDFW inventory that intersected with the assumed fish distribution (Figure A-6). The final list of obstructions was reviewed and approved by WDFW for use in this analysis. The list includes a total of 470 total obstructions (natural and artificial) including 369 culverts (Figure A-7). There are many additional culverts and potential barriers in the Chehalis Basin that exist outside the currently assumed distribution of the five modeled salmonids. Obstructions in the WDFW dataset that were not included in the EDT model may be in agricultural drainage systems, urban areas, or other areas not connected to the modeled stream network. The model also excludes areas that may contain sea-run Cutthroat trout including small tributaries that are not typical salmon habitat. The SWIFD dataset that was used to define the fish distribution is being updated by WDFW and tribes. The updated distribution is likely more expansive than the current SWIFD; the updated SWIFD and the WDFW culvert inventory will likely identify additional obstruction that will need to be included in the next update of the Chehalis EDT model.

Fish passage ratings for most obstructions were provided by WDFW. In the WDFW inventory, obstruction ratings for upstream adult fish passage were designated 0% (impassable), 33% passable, 66% passable, or 100% passable by adult salmonids (WDFW 2009). Where provided by WDFW, these ratings were used for all species in the 2016 EDT model. For culverts that have not been rated for passage by WDFW, an adult salmonid upstream rating of 50% passage was assumed for all species. Downstream passage of juveniles was assumed to be 100% for all obstructions. The location and passage assumption for each obstruction in the 2016 EDT model can be viewed at the EDT attribute mapping site.[9]

[9] http://ecosystems.azurewebsites.net/chehalis2016edt/

Figure A-7
Distribution of Modeled Culverts in the Chehalis EDT Model*



*Data associated with each culvert can be viewed at http://ecosystems.azurewebsites.net/chehalis2016edt/

4.2.5 Empirical Habitat Data

EDT evaluates stream habitat at a reach scale. Figure A-2 shows the data inputs to EDT that characterize environmental conditions in each reach that are shaped across months within a year. Empirical data is standardized to a set of index values (Box 3). EDT also characterizes reach-level conditions using habitat types that are entered as the percent area of the stream reach (Figure A-1). Habitat type refers to physical stream unit types such as pools and riffles.

The 2014 and 2016 Chehalis EDT models incorporated information from the 2003 model. In the 2003 model, the attributes in Table A-1 were parameterized based on published watershed assessments including Phinney and Bucknell (1975a, 1975b), Wampler et al. (1993), and Smith and Wegner (2001), and were supplemented where needed by expert knowledge from WDFW.

The 2016 Chehalis EDT model retained much of the data from the 2003 model to characterize conditions in the tributaries (e.g., Newaukum River). More recent data on conditions in the tributaries was incorporated when available. This included information data from WDFW RiverScape surveys (Zimmerman and Winkowski 2016) that assessed habitat conditions in parts of the Newaukum, upper Chehalis, and Satsop sub-basins. Information on large wood collected by Anchor QEA in the upper watershed in the area of the proposed dam (Goldsmith 2016) was also included.

In contrast to conditions in the tributaries, conditions in the mainstem Chehalis River and the upper Chehalis sub-basin (the area most directly affected by potential dam construction) has been refined and updated in the 2016 model to include new information and linkages to physical models that provide flow, channel width, and temperature (Section 4.2.6, Modeled Habitat Data, and Figure A-2). Physical habitat features in the upper Chehalis and much of the mainstem was updated using information from a PHABSIM (Physical Habitat Simulation System, Bovee et al. 1998) assessment conducted as part of the Chehalis Flood Control Study (Normandeau Associates 2012) as well as results from the WDFW RiverScape surveys (Zimmerman and Winkowski 2016).

This compiled information was used to create ratings for each environmental attribute using the EDT attribute rating system described by Lestelle (2004). All ratings for the 2016 baseline condition in EDT can be viewed spatially and across months at the EDT attribute mapping site.[10]

4.2.6 Modeled Habitat Data

Ratings for several of the key parameters for mainstem reaches in the 2016 EDT model were derived from physical process models outside of EDT described in Section 3 (Figure A-2). These models provided a quantitative basis for derivation of temperature, flow, and inundated floodplain extent that was used to derive baseline values and to capture future alternative conditions. Modeled data were checked against direct measurements where available.

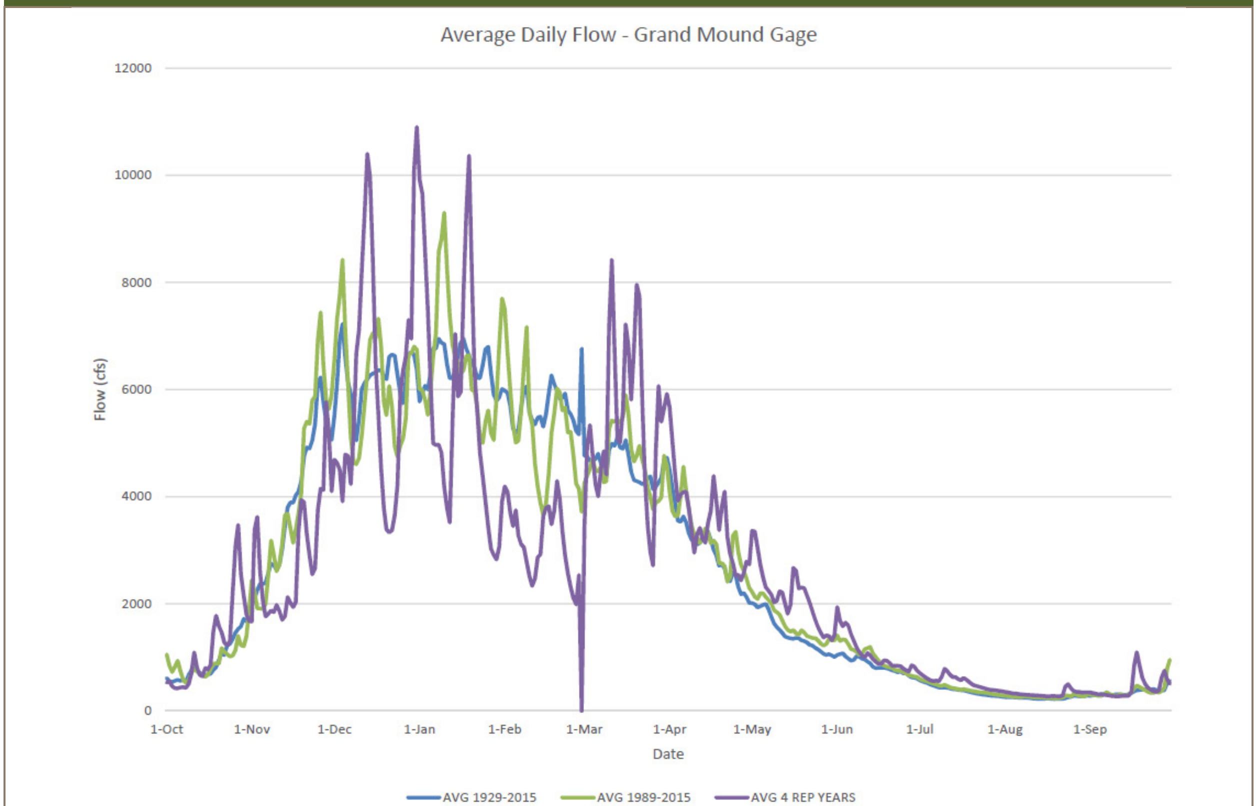
[10] http://ecosystems.azurewebsites.net/chehalis2016edt/

4.2.6.1 Flow and Channel Width

EDT has four attributes directly related to the change in flow as a result of a scenario relative to the historic condition (Table A-1): change in peak flow, base flow, diel variation in flow, and intra-annual variation or flashiness relative to the pre-development condition. These parameters are shaped across months to reflect the annual hydrograph. In addition, flow is a fundamental attribute that affects several other physical parameters in EDT. An important flow-dependent attribute is channel width, a key factor affecting biological carrying capacity that is a function of flow and channel configuration.

The direct flow attributes, annual hydrograph, and channel width for the mainstem Chehalis River were derived from HEC-RAS analysis performed by (Anchor QEA (Adam Hill). Five water year conditions were modeled based on the 1989–2015 flow at Grand Mound to represent very dry (2001), dry (2005), normal (2014), wet (2011), and very wet (1997) conditions. Modeled conditions were used to derive a "normal" flow pattern for the baseline condition for the PEIS analysis. Each flow year has its own peculiarities and no condition represents the ideal baseline shape for flow and channel width. For this reason, results from the HEC-RAS analysis of the four extreme conditions (very dry, dry, wet, and very wet) were averaged to represent the baseline condition for the PEIS analysis (Figure A-8).

Figure A-8
Average HEC-RAS Modeled Flow in the Chehalis River at Grand Mound*

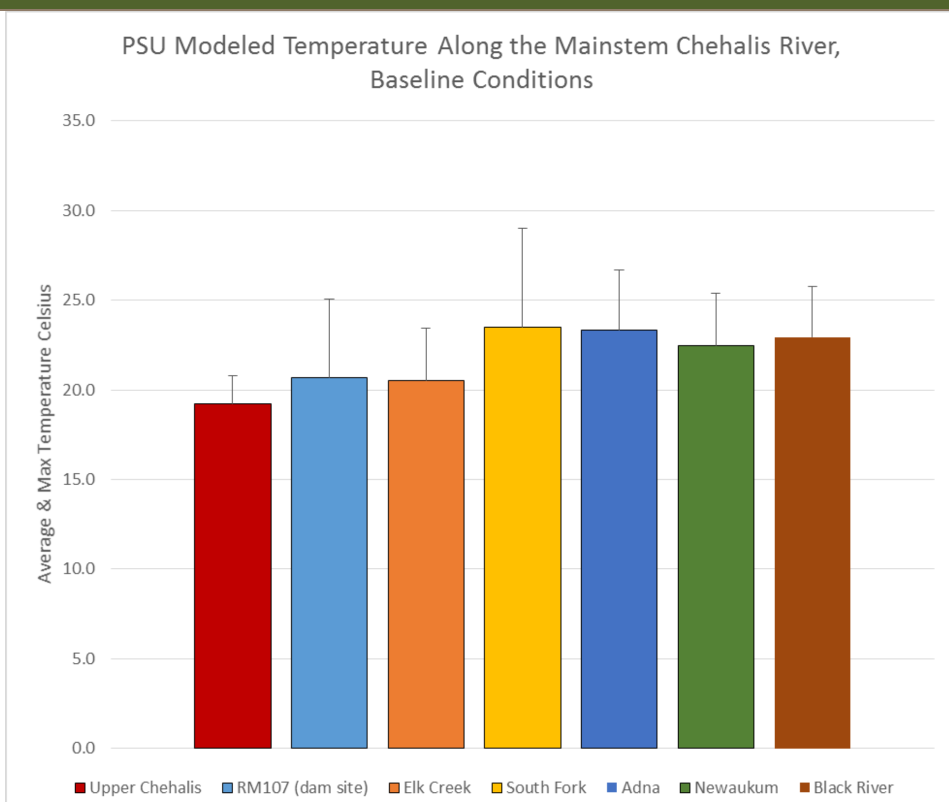


Note:
*The 4 year average was used to shape flow and related attributes in EDT (note that the extreme dip in flow on March 1 is a marker and not actual modeled flow)

4.2.6.2 Temperature

The Chehalis River is characterized by very warm summer water temperatures that have been identified as a key factor limiting fish production and distribution (Smith and Wenger 2001). Until recently, systematic collection of temperature data, especially in tributaries, was limited. However, starting in 2014, WDFW, Washington Department of Ecology, and Anchor QEA installed temperature monitoring devices at several points across the Basin; a more extensive network of temperature monitoring sites was deployed in 2015. In addition, as part of the 2016 analysis, the PSU CE-QUAL-W2 temperature model provided all temperature data from the mainstem Chehalis River under current and future conditions (Van Glubt et al. 2016). This model was used to create the current conditions temperature rating attributes for the mainstem Chehalis reaches in the 2016 EDT model as well as temperature ratings for the dam operational scenarios and all future modeled conditions, including future climate conditions. Results from the PSU model show August water temperatures peak at the confluence of the South Fork Chehalis River where daily maximum temperature under current conditions reached 29° Celsius (Figure A-9). Development of temperature data for historic conditions is underway, but was not available for incorporation in the 2016 Chehalis EDT model.

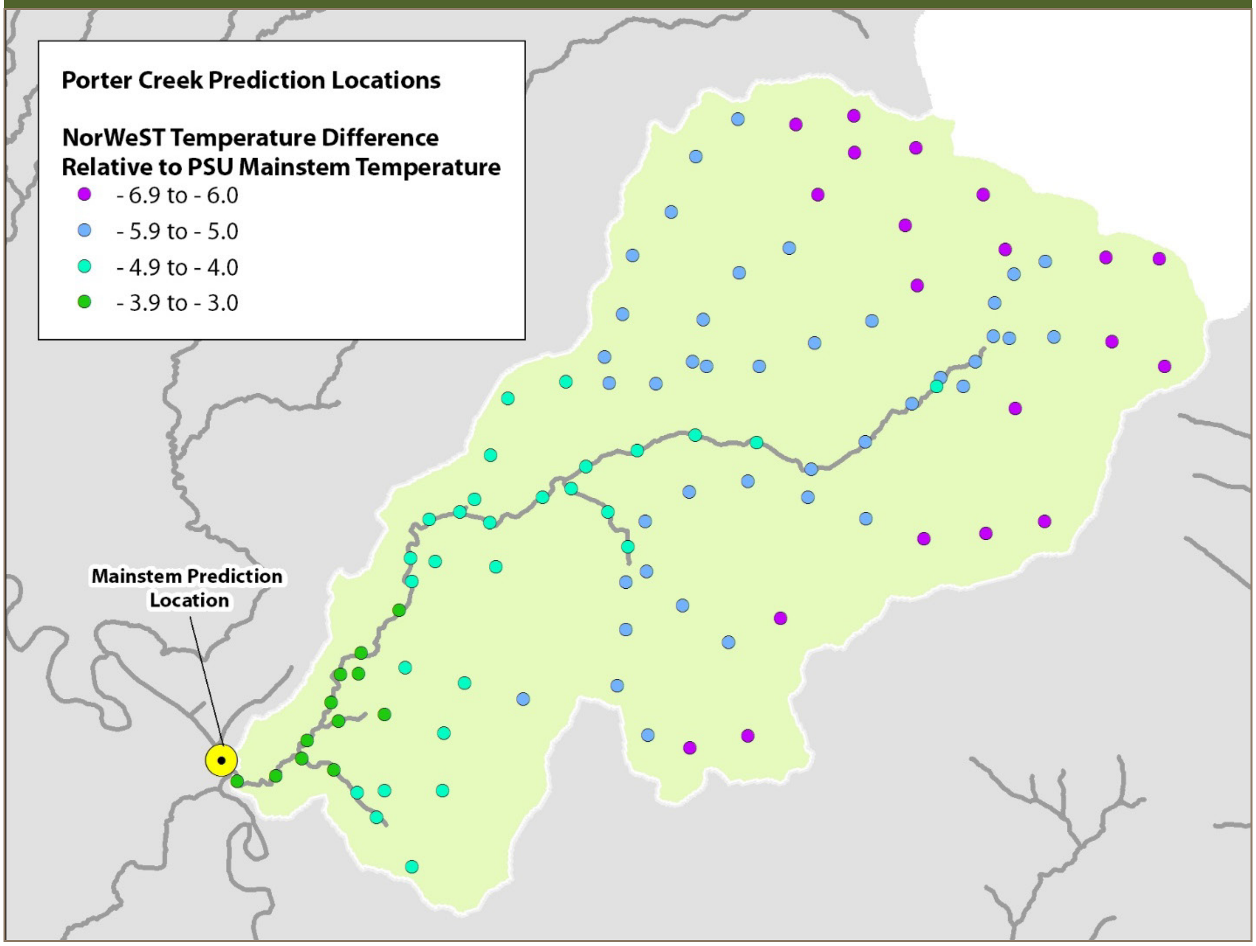
Figure A-9
Average Daily Summer Water Temperature Along the Chehalis River Mainstem Under Current Habitat Conditions as Modeled by PSU*



Note:
*Bars show the August monthly average in the mainstem at each point or tributary confluence. Whiskers shows maximum daily temperature at each point

The PSU model provided temperatures in the mainstem Chehalis, but did not extend into the tributaries. To capture tributary temperature conditions, the PSU model results were combined with the U.S. Forest Service NorWeST temperature model for the Chehalis Basin. NorWeST provides temperature models for streams across the Pacific Northwest using spatial statistical techniques and available empirical data (Isaak et al. 2014). Average August maximum temperature is calculated in the NorWeST model for a variety of current and future conditions. To calculate temperature in each tributary stream reach, the longitudinal spatial pattern of the NorWeST data was applied to the PSU modeled mainstem temperature at the confluence. A monthly pattern from the PSU temperature data was then applied to the tributary temperature differentials to obtain the monthly ratings (Figure A-10).

Figure A-10
Example of Temperature Differentials Across the Porter Creek Drainage as Modeled by NorWeST (Tributaries) and Mainstem Temperature from PSU Model



The daily modeled data was used to derive monthly temperature ratings for EDT for each reach in the tributaries (Box 3). These ratings are based on criteria that attempt to capture the monthly experience of fish in a reach including peak daily temperature and number of days of exposure to temperature

(Table A-4). These criteria are based on the Environmental Protection Agency temperature criteria for pacific salmon (McCullough et al. 2001).

Table A-4
Categorical Rating Definitions for Daily Maximum Temperature by Month

0	1	2	3	4
Warmest day < 10°C	Warmest day > 10°C and < 16°C	> 1 day with warmest day 22–25°C or 1–12 days with > 16°C	> 1 day with > 25–27.5°C or > 4 days (non-consecutive) 22–25°C or > 12 days with > 16°C	> 1 day 27.5°C or 3 days (consecutive) > 25°C or > 24 days > 21°C

The modeled temperature in the tributaries was compared to the WDFW data from 2014–2016. The WDFW data was available in several reaches throughout the Basin but very few sites had data for all 12 months, and data for the critical summer months was lacking for many sites. However, the fit was acceptable and the procedure provided temperature ratings for all reaches in the Chehalis model that could be responsive to future climate conditions. Modeled data for Skookumchuck River bears further scrutiny—NorWeST-based estimates of temperature in the Skookumchuck resulted in relatively high EDT ratings (greater than 3.5, see Table A-4) from below the dam to the mouth of the river. Water releases from the dam were expected to be cold and result in relatively lower (better) rating for the Skookumchuck below the dam. Compared to EDT ratings derived from the WDFW data, results were similar due to the occasional day of recorded high water temperature. As a result of the higher temperature ratings, EDT estimates of habitat potential for spring-run Chinook salmon in the Skookumchuck River were noticeably lower than estimates of actual spawning. Other information indicates that the Skookumchuck is cooler than other streams (Liedtke et al. 2016). This discrepancy may be resolved in subsequent work.

4.2.6.3 Bed Scour

Bed scour refers to the depth of substrate sediment (bed load) displaced by high flow events. Bed scour can destroy salmon redds and is recognized as an important limiting factor for salmon (Montgomery et al. 1996). High levels of bed scour and bed load movement have been observed in the Chehalis River, particularly in the mainstem downstream of Crim Creek, as a result of redistribution of sediment mobilized by flooding (Watershed GeoDynamics 2012). However, bed scour is not reported to be a pervasive problem across the watershed. Bed scour can occur at very local levels, but in this case average bed scour across a reach needs to be rated. Moreover, bed scour is a difficult attribute to measure quantitatively, especially over large areas such as the entire Chehalis Basin, and very few measurements of bed scour have been made.

In the absence of quantitative data on bed scour at a reach scale across the Basin, a procedure was developed for estimating a bed scour rating in EDT based on a general bed scour hypothesis. An expert panel (Box 4, Section 6.1) was convened to identify the relationship between bed scour and other attributes in the EDT model for which data was available. The panel identified six attributes in EDT as key controllers on bed scour and weighted the attributes in terms of their control on bed scour at a reach scale (Table A-5). These weights were then used to calculate a weighted average rating for each reach and month based on the parameter values (by reach and by month) for the attributes in Table A-5. The panel hypothesized that large wood was a primary controller on bed scour at a reach scale (i.e., more wood results in less bed scour). Higher levels of channel confinement, both natural and artificial, were also hypothesized to contribute to bed scour.

The bed scour rating is calculated as the sum (adjusted attribute ratings)/sum (weights). The example in Table A-5 is for a reach with little or no large wood (attribute rating = 4), artificially confined (hydromodification[11] = 3), and a low level of change in peak flow (attribute rating 1). The resulting bed scour rating of 2.7 would result in a lowered egg survival in this reach, largely as a result of very low levels of large wood.

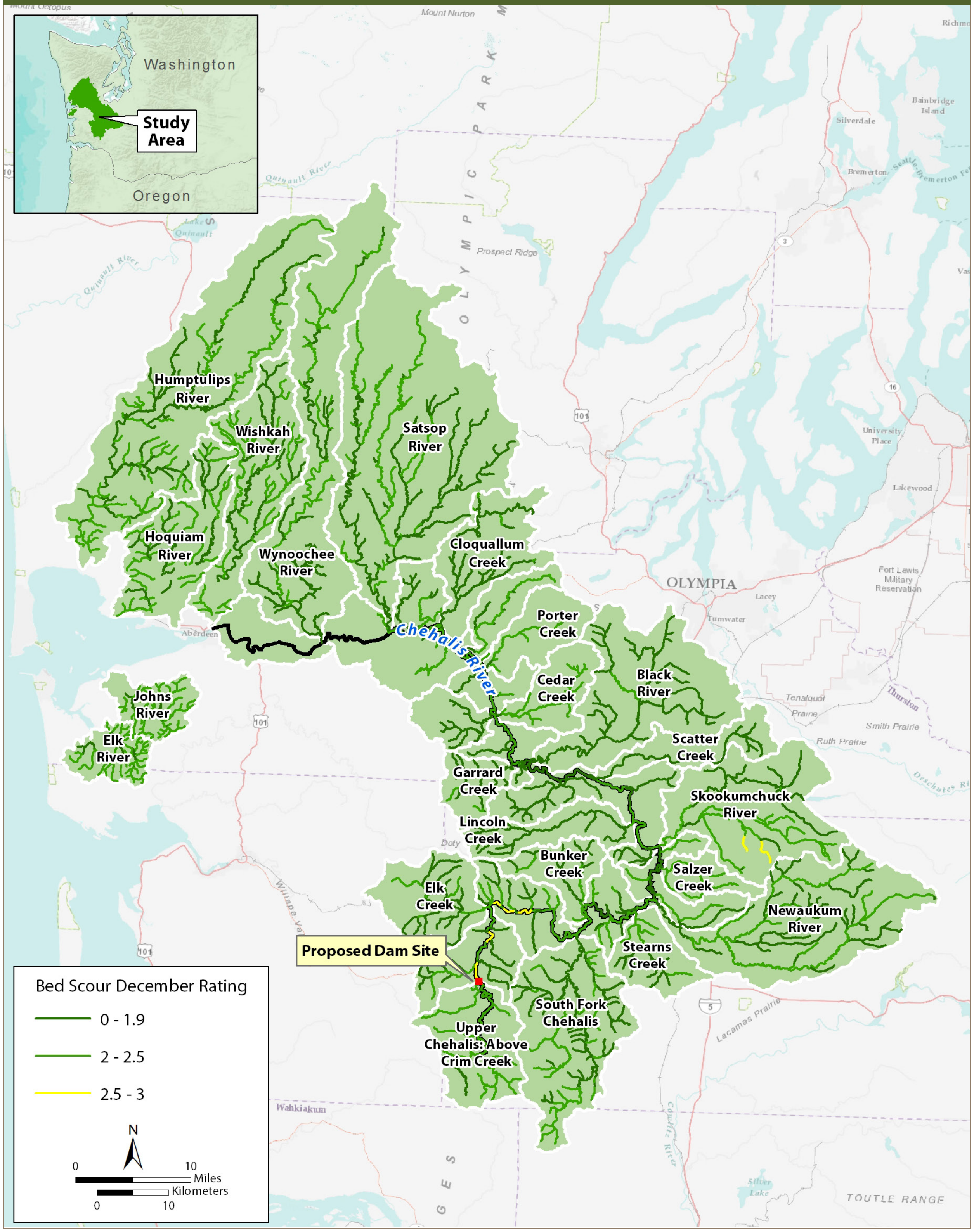
Table A-5
Hypothesized Controls on Bed Scour and Relative Weights with Example Calculation of EDT Bed Scour Rating

CORRELATES	WEIGHT	EXAMPLE ATTRIBUTE RATINGS	ADJUSTED ATTRIBUTE RATINGS
Wood	0.85	4	3.4
Gradient	0.2	2	0.4
Natural Confinement	0.69	2	1.4
Channel Complexity	0.38	3	1.2
Hydromodification	0.54	3	1.6
Flow Peak Change	0.53	1	0.5
		Bed Scour Rating	**2.7**

This procedure resulted in ratings for bed scour for each reach and month across the Chehalis Basin that comport with available published information (Watershed GeoDynamics 2012; Nelson and Dube 2015). Most reaches received ratings that had little effect on survival (EDT ratings less than 2) because of low gradient and confinement. Higher ratings (greater negative effect on survival) were calculated in the more confined and higher-gradient upper Chehalis area downstream to the South Fork as well as the upper Newaukum and South Fork (Figure A-11).

[11] Hydromodification refers to artificial confinement of the channel due to rip-rap, dikes, or extreme incision.

Figure A-11
Calculated Bed Scour Ratings for the Chehalis Basin the Month of December



4.2.6.4 Floodplain and Secondary Channels

A major refinement of the Chehalis EDT model in 2016 has been improved information on the current and historic floodplain, off-channel habitat, and secondary channel habitat. These habitats provide important winter rearing areas for juvenile salmonids especially for coho salmon (Bustard and Narver 1975; Henning 2005; Lestelle 2007). The nature of the Chehalis River is that much of the mainstem meanders across a broad, low-gradient floodplain, which supports the idea that large expanses of these types of habitats were typical of the historic condition. Much of this habitat has been lost as the river has been isolated from its floodplain due to channel incision and diking.

Three sources of data on floodplain habitat extent were developed in 2016.

1. 2-D HEC-RAS modeling provided by WSE (Larry Karpack).
2. Analysis of aerial photography and historic General Land Office maps by NMFS (Tim Beechie).
3. Analysis of LiDAR and GIS by Natural Systems Design (Tim Abbe).

These sources were used to derive estimates of the extent in square meters of off-channel habitat by reach throughout the Chehalis Basin for the current and historic conditions.

Current Condition. Floodplain features along the mainstem Chehalis River were derived from 2-D and 1-D HEC-RAS (Karpack 2016). Because of the intensive calculations required for 2-D modeling, WSE was only able to provide estimates at a few key locations along the river. These select locations are shown in Figure A-12. Modeling was done across a range of flows, thereby providing flow-flooding relationships that were used to calculate floodplain extent at any flow. An example of a flow-inundation relationship derived from the 2-D HEC-RAS for the Black River confluence is shown in Figure A-13.

The remainder of the mainstem and tributary floodplain extent in the current condition was based on static estimates from NMFS analysis of aerial photography and maps (Beechie 2016). NMFS estimates of inundation during a typical high flow month were adapted across months based on the hydrograph. The results along the mainstem reaches at various flows is shown in Figure A-14.

Figure A-12
Watershed SE 2D Modeling Locations and Example of Estimated Inundation at the Black River Confluence

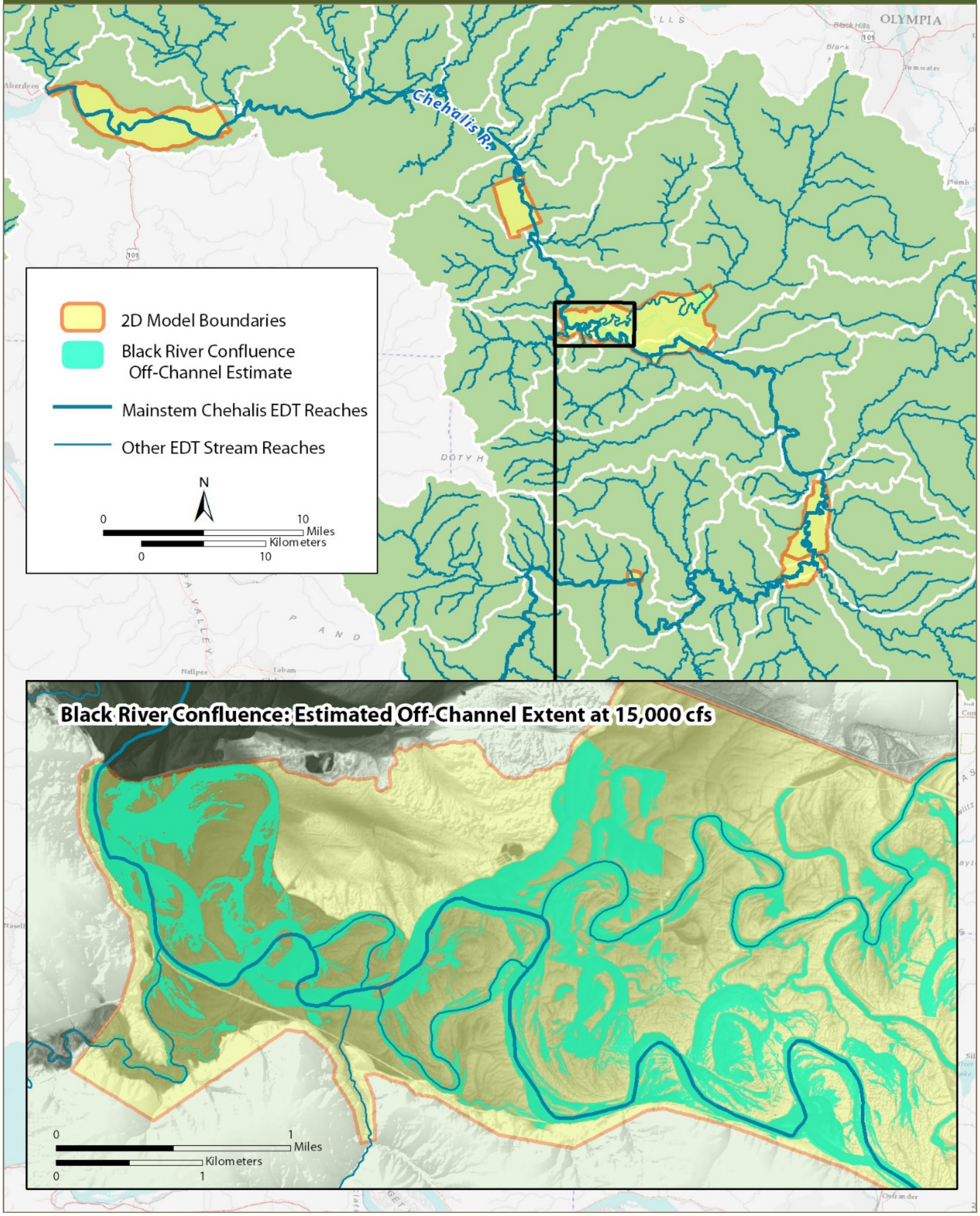


Figure A-13
Inundation-flow Relationship Derived from 2-D HEC-RAS Modeling at the Confluence of the Black River (WSE)

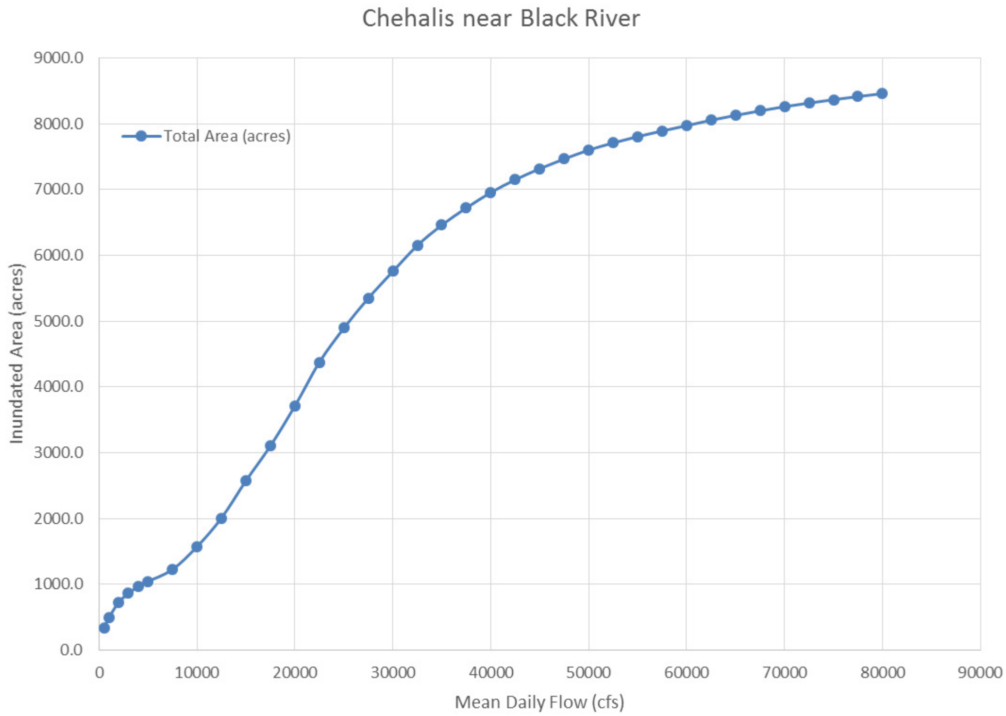
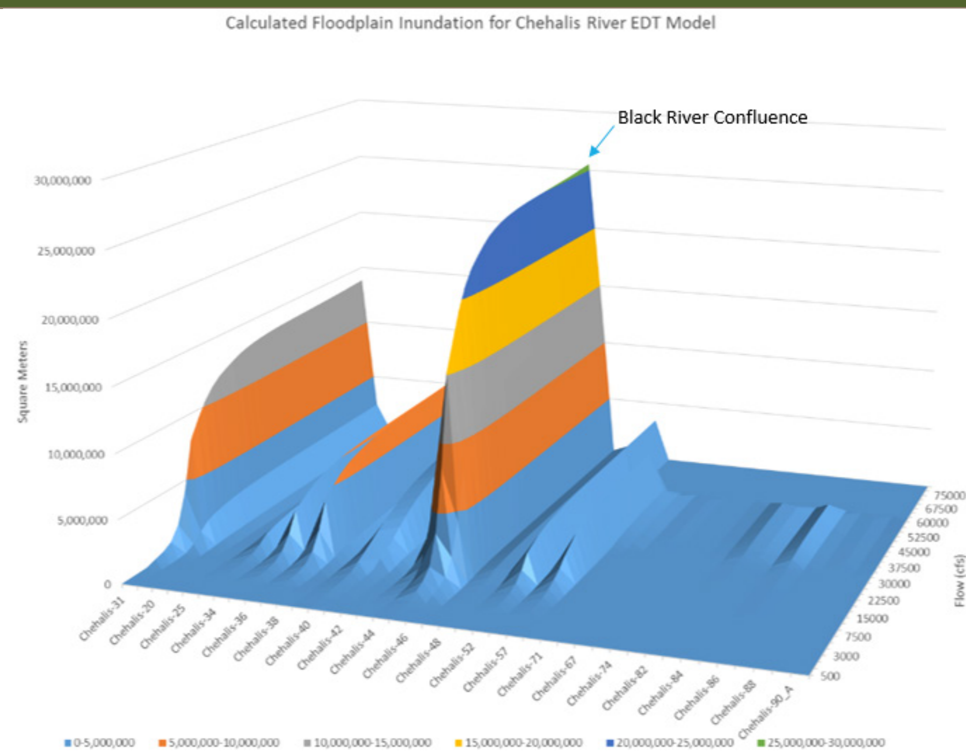


Figure A-14
Estimated Extent of Floodplain Inundation as a Function of Flow, Derived from 2-D HEC-RAS Modeling (WSE)



4.2.6.5 Smolt-to-Adult Returns

The smolt-to-adult return (SAR) is the survival of fish from juveniles entering Grays Harbor to returning adults leaving Grays Harbor and ascending streams and rivers of the Basin. SAR is used in EDT to complete the life-history trajectories and link the modeled freshwater habitat for emigrating juveniles to the same freshwater habitat for returning adults. In the Chehalis model, the SAR captures survival conditions in Grays Harbor and the ocean including harvest. SAR estimates for each species were provided by WDFW (Zimmerman 2016). Spring-run and fall-run Chinook salmon SAR ranges were based on hatchery survival estimates for the Chehalis system. The coho salmon and steelhead SAR are based on data from Bingham Creek.

Table A-6
Smolt-to-Adult Return (SAR) Values Used in the EDT Model, and the Range of SAR Values Recommended by WDFW

SPECIES	SAR	WDFW RANGE
Spring-run Chinook Salmon	0.55%	0.1–1.5%
Fall-run Chinook Salmon	0.63%	0.1–1.5%
Coho Salmon	5.94%	1–9%
Steelhead	14.85%	3–13%
Chum Salmon	0.50%	Not provided

5 MODEL VALIDATION

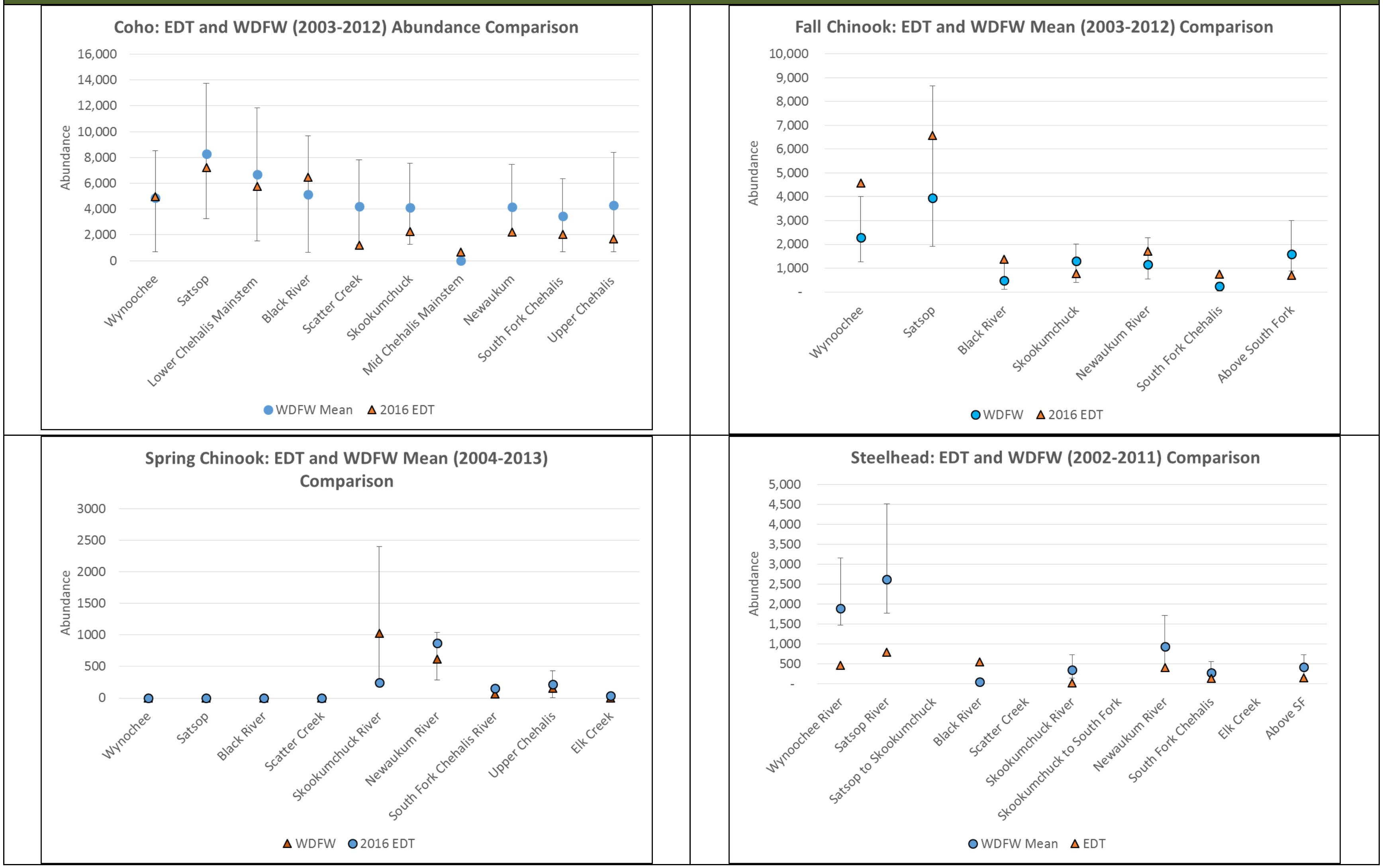
The habitat-based estimates of adult fish abundance from the Chehalis EDT model for each population were compared to recent WDFW fish population estimates (time period varies by species from 2002 to 2013) to evaluate model performance. Comparing the two independent estimates of fish abundance in the Chehalis Basin provides one form of validation of the Chehalis EDT model.

The spatial structure for each species across tributary watersheds is compared between the EDT habitat-based estimates and the WDFW fish population data in Figure A-15. Because of difficulties with aligning the WDFW survey areas with EDT spatial structure, only the tributary data is included in Figure A-15. For this type of comparison, the pattern across sub-basins is more revealing than the total abundance. The return of anadromous salmonids to the Chehalis Basin varies widely between years due to variation in marine survival, harvest, and other factors. However, the differences in abundance between sub-basins reflect the underlying pattern of habitat condition and the ability of the EDT model to convert habitat conditions into VSP population performance parameters.

With some exceptions, the habitat-based estimates of spatial structure follow the WDFW population estimates for each tributary. The similarity between habitat-based abundance and WDFW data is particularly close for coho salmon. EDT habitat-based estimates of abundance for fall-run Chinook salmon generally follow the pattern of WDFW population estimates although EDT values tend toward the high side of observed abundance in the Satsop and Wynoochee sub-basins. EDT estimates of habitat potential for spring-run Chinook salmon generally align with the WDFW estimates, with the exception of the Skookumchuck River, where the EDT estimate of habitat potential is noticeably lower than the range of WDFW observed abundance. This is largely due to the assumed high temperature in the Skookumchuck, which lowered the habitat potential. The data that was used to derive temperature inputs to EDT in the Skookumchuck River may be in error and should be re-examined. For steelhead, EDT appears to appreciably underestimate the habitat potential in the Satsop and Wynoochee systems, but aligns well with the WDFW data in other tributaries. Because of expected changes in the Washington SWIFD system, the distribution of fish assumed in the EDT model will likely change in the future, which will affect the degree of alignment between modeled habitat potential and observed spawning distribution.

In general, there was a high degree of alignment between the habitat-based estimates of abundance from the EDT model and the estimates of abundance from observational data from WDFW given that the two datasets are completely independent. EDT is based on observed and modeled information on habitat conditions and an assumed pattern of use by each species, while the WDFW data is based on expansion of data on abundance of redds and fish observed in index reaches. Both datasets are measurements with error and there is no reason to expect exact convergence of the estimates. Nonetheless, the alignment between the EDT habitat-based estimates of abundance and WDFW fish count data suggests that the Chehalis EDT model captures how current habitat conditions shape the abundance and distribution of salmonids in the Chehalis River. Based on this alignment between the empirical and modeled estimates of spawner abundance, EDT was judged to be useful for the assessment of flood damage reduction and restoration measures.

Figure A-15
Species Level Comparison of EDT Habitat-based Estimates and WDFW Estimates of Spawning Escapement*



* WDFW data is shown as the 10-year mean with whiskers showing the maximum and minimum values

6 PARAMETERIZING HABITAT RESTORATION ACTIONS IN THE CHEHALIS EDT MODEL

This section describes an analytical framework for characterizing the environmental effects of actions that change the condition of aquatic habitat. The process primarily applies to parameterization of habitat restoration actions in the EDT model for the PEIS. While this discussion focuses on actions intended to restore habitat conditions, the procedure also applies to actions that degrade habitat conditions. In this context, restoration is in the improvement of current conditions toward the historic condition while degradation is the deterioration of conditions away from the historic condition.

The Aquatic Species Habitat Actions (ASHA) are restoration actions to improve current conditions in ways that benefit anadromous salmonids. Capturing restoration actions in EDT involves computing changes in environmental conditions (e.g., flow, temperature, large wood structure) expected to result from restoration; these changes are then interpreted biologically by the model.

6.1 Characterizing Actions in EDT for the PEIS

Actions such as habitat restoration, flood damage reduction scenarios, and climate change were modeled as changes in habitat potential relative to the current condition. The effect of the actions on some attributes, such as water temperature, could be predicted using quantitative models such as the CE-QUAL-W2 model (Figure A-2). However, quantitative models were not as effective for predicting the effect of some actions, such as restoration of riparian areas that affect multiple environmental attributes in the model. In the Chehalis analysis, the process of capturing actions in EDT for which there were no available quantitative models relied on hypotheses developed by a panel of experts in restoration and stream ecology (Box 4). The hypotheses were used to identify how current

Box 4: Use of Expert Panels in the PEIS

The Chehalis EDT model was parameterized using several types of information, including the use of expert knowledge. Expert knowledge was used where empirical data was incomplete or lacking, or where a quantitative model was not available. Expert knowledge was developed using a systematic process to create hypotheses that linked actions (e.g., riparian restoration) to an expected change in EDT attribute values. A panel of experts in restoration ecology was convened to first, map the action onto EDT environmental attributes and second, make conclusions regarding the effectiveness of the action to change the linked EDT attributes. Examples of the expert-derived hypotheses are found throughout this document.

Experts that contributed to development of the hypotheses include the following (participation varied based on topic):

Dr. Tim Abbe, Natural Systems Design
Dr. Tim Beechie, NMFS
Dr. Kathy Dube, Watershed Geodynamics
Mr. Tracy Drury, Anchor QEA
Dr. John Ferguson, Anchor QEA
Mr. Larry Lestelle, BioStream
Dr. Chip McConnaha, ICF
Dr. Tim Quinn, WDFW
Mr. David Price, WDFW

environmental attribute ratings such as large wood and temperature would be changed by project actions (e.g., riparian area restoration).

6.2 Methodology

This framework for characterizing how restoration actions could affect the environment, and the performance of salmon, is based on three concepts.

- Restoration Potential
- Effectiveness of Restoration Actions
- Intensity Scalar

Restoration potential defines what is possible in regard to restoration of environmental conditions in a stream reach and is bounded by the current and historic condition of an attribute (e.g., large wood) in a reach and in a month. Limiting the potential to restore an attribute by the historic condition accounts for intrinsic characteristics of the watershed. If the current condition is very good, meaning very close to the historic condition, then there is relatively little restoration potential. On the other hand, there is higher restoration potential (more room for improvement) if the current condition is very poor compared to the historic condition.

The concept of restoration potential is illustrated in Figure A-16 and Figure A-17 which shows the rating of an environmental attribute (e.g., LWD) in a reach under Current and Template (historic) conditions. Note that EDT ratings scale the amount of survival degradation that occurs as a result of an environmental condition (Box 3). A rating of 0 means a very good condition for the attribute (i.e., no degradation of survival) while a 4 means a very poor condition for the attribute (i.e., extreme degradation of survival). In Figure A-16, the current rating for the attribute in a stream reach is 3 while the historic condition of the attribute is 1. These two conditions define the restoration potential as the distance between the current and historic conditions. Restoration would improve the current condition and move it towards the historic condition as shown in Figure A-17. The amount of change in the condition of an attribute expected from a restoration action is computed as the product of the effectiveness of the action and the intensity scalar (shown by the red box in Figure A-17). This product of effectiveness and intensity is referred to as the adjusted effectiveness.

Figure A-16
Depiction of the Restoration Potential Concept Showing Hypothetical EDT Ratings for an Attribute (e.g., LWD) in a Reach for the Current and Historic Conditions

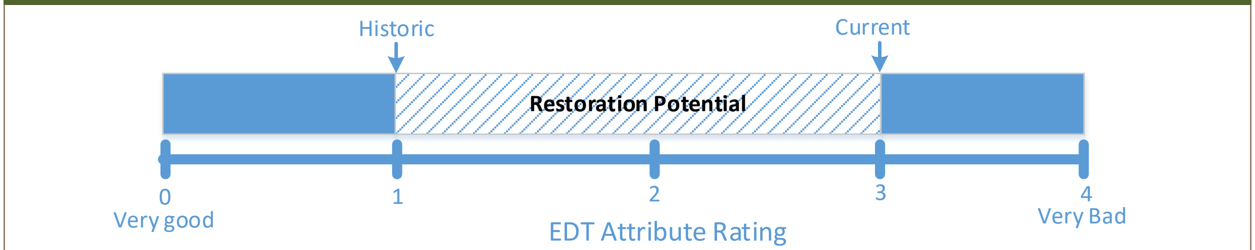
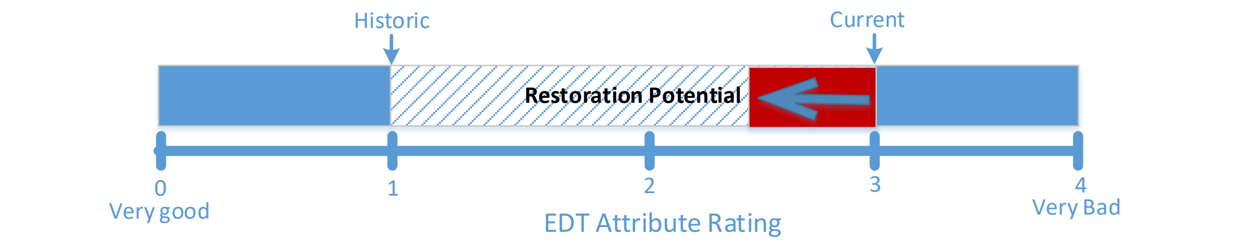


Figure A-17
Effect of a Restoration Action (e.g., riparian restoration) on the Rating for an EDT Environmental Attribute (e.g., LWD) in a Stream Reach



Note:
The red box depicts the adjusted effectiveness of the action to change the rating of the attribute.

<u>Effectiveness</u>. Effectiveness is defined as the theoretical maximum amount of improvement or degradation of environmental attributes (e.g., large wood, temperature) that is possible to achieve by implementing a type of restoration action (e.g., riparian restoration). Effectiveness is a scientific statement regarding the type of action without regard to a specific project or considerations of cost, feasibility, or opportunity. For the Chehalis flood control study, a group of experts (Box 4) was convened to derive effectiveness values for types of restoration actions that are relevant to the ASHA. The role of this group was to do the following.

1. Associate categories of restoration actions (e.g., riparian restoration) with one or more environmental attributes in EDT (e.g., riparian function, LWD)
2. Rate the strength of effect of the action on the attribute

Participants characterized the effectiveness using a numeric scoring system. The scores were averaged across participants and converted to a -1 to 0 to +1 value (negative values indicated the action would degrade the current condition relative to the historic condition and positive values indicated the action would restore the current condition relative to the historic condition). The result was a conceptual model of the effect actions on the aquatic environment.

Conceptual models of action effectiveness were developed by the expert panel for the following.

- Large wood restoration (Figure A-18)
- Floodplain reforestation (Figure A-19)
- Riparian buffer restoration (Figure A-20)
- Downstream effect of the FRFA (Figure A-21) and FRO (Figure A-22) facilities
- Climate change (Figure A-23)

Figure A-18
Conceptual Model of the Effectiveness of Large Wood Restoration to Affect Attributes in the EDT Model

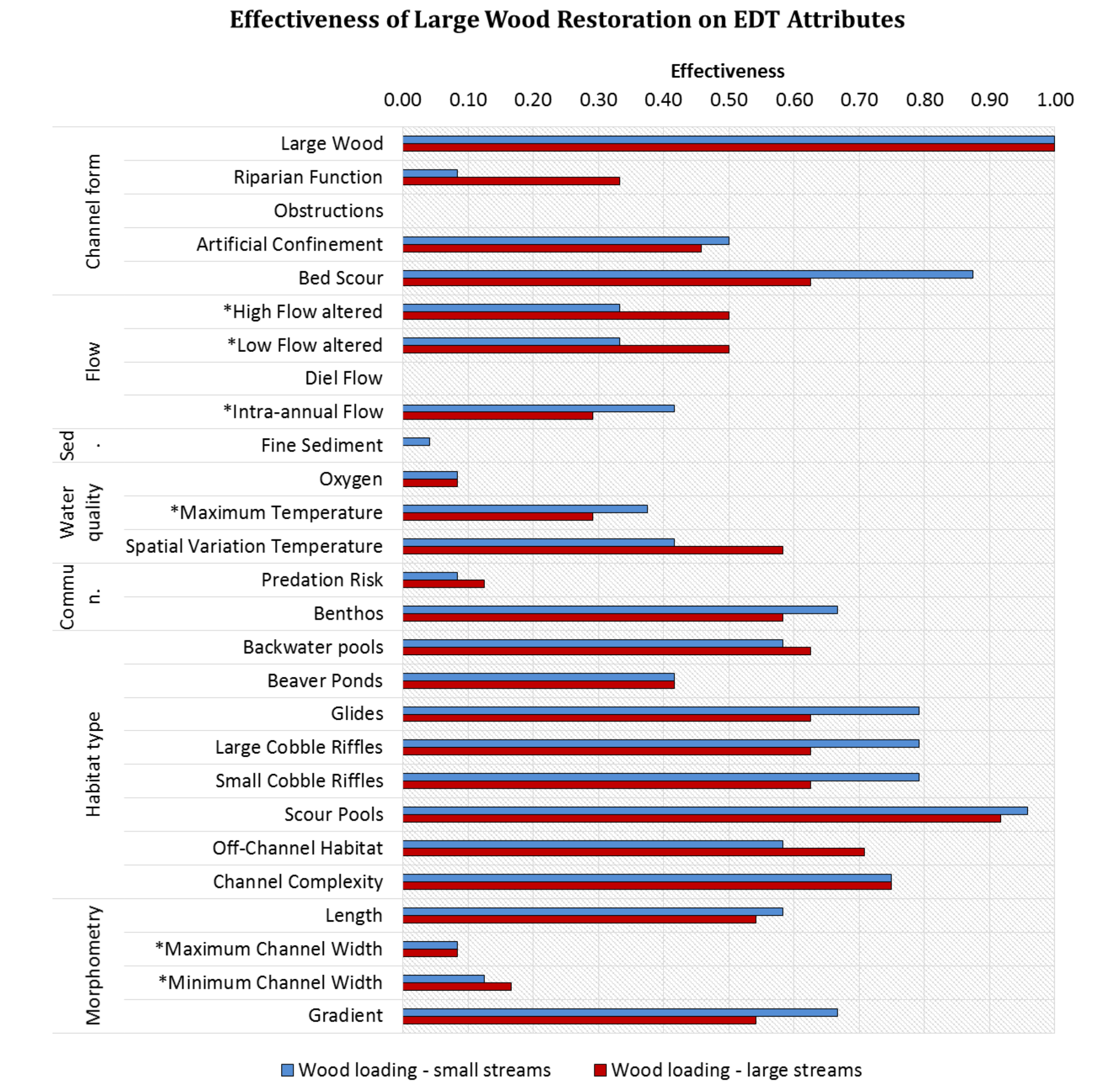


Figure A-19
Conceptual Model of the Effectiveness of Floodplain Reforestation to Affect Attributes in the EDT Model

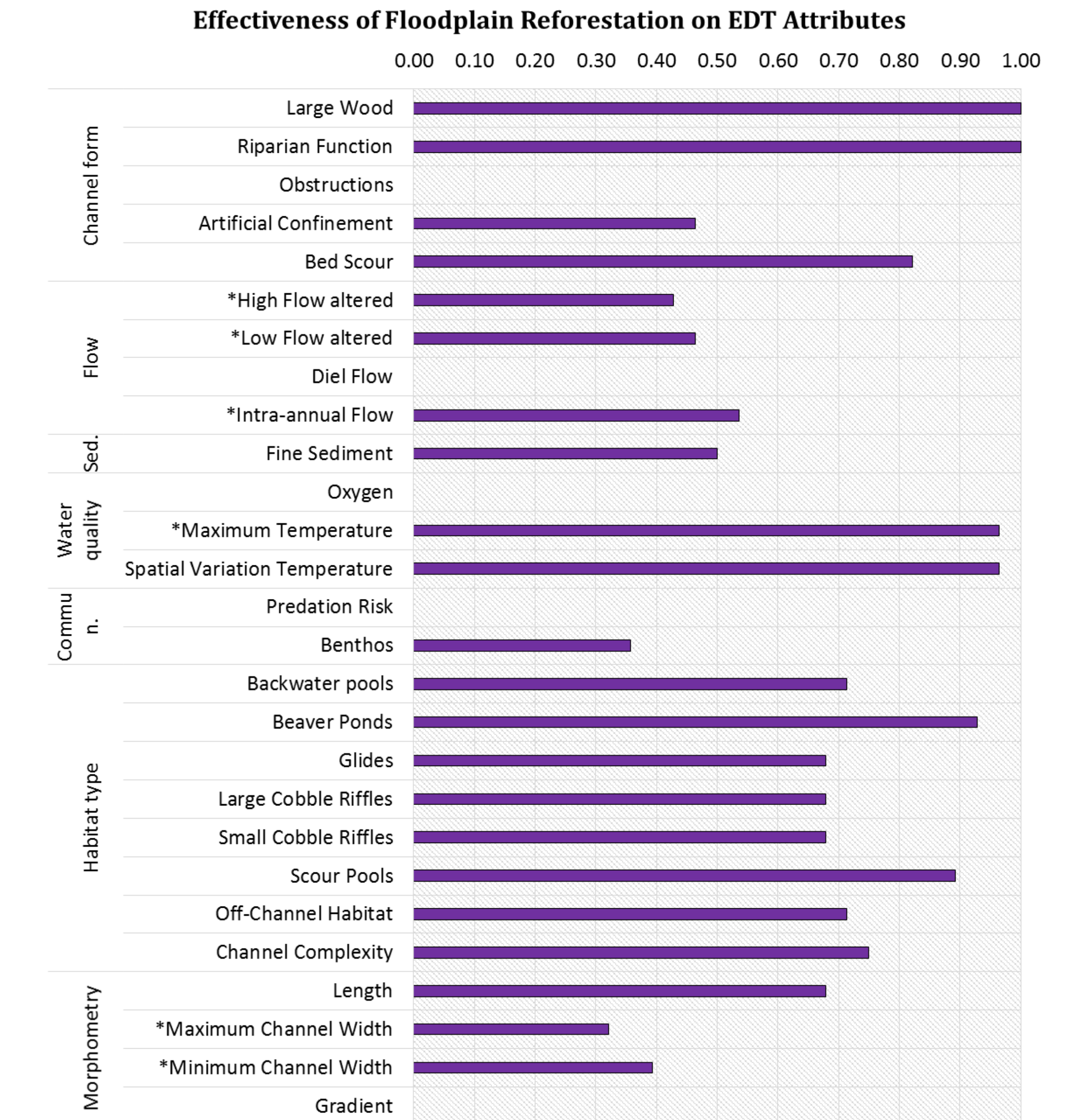
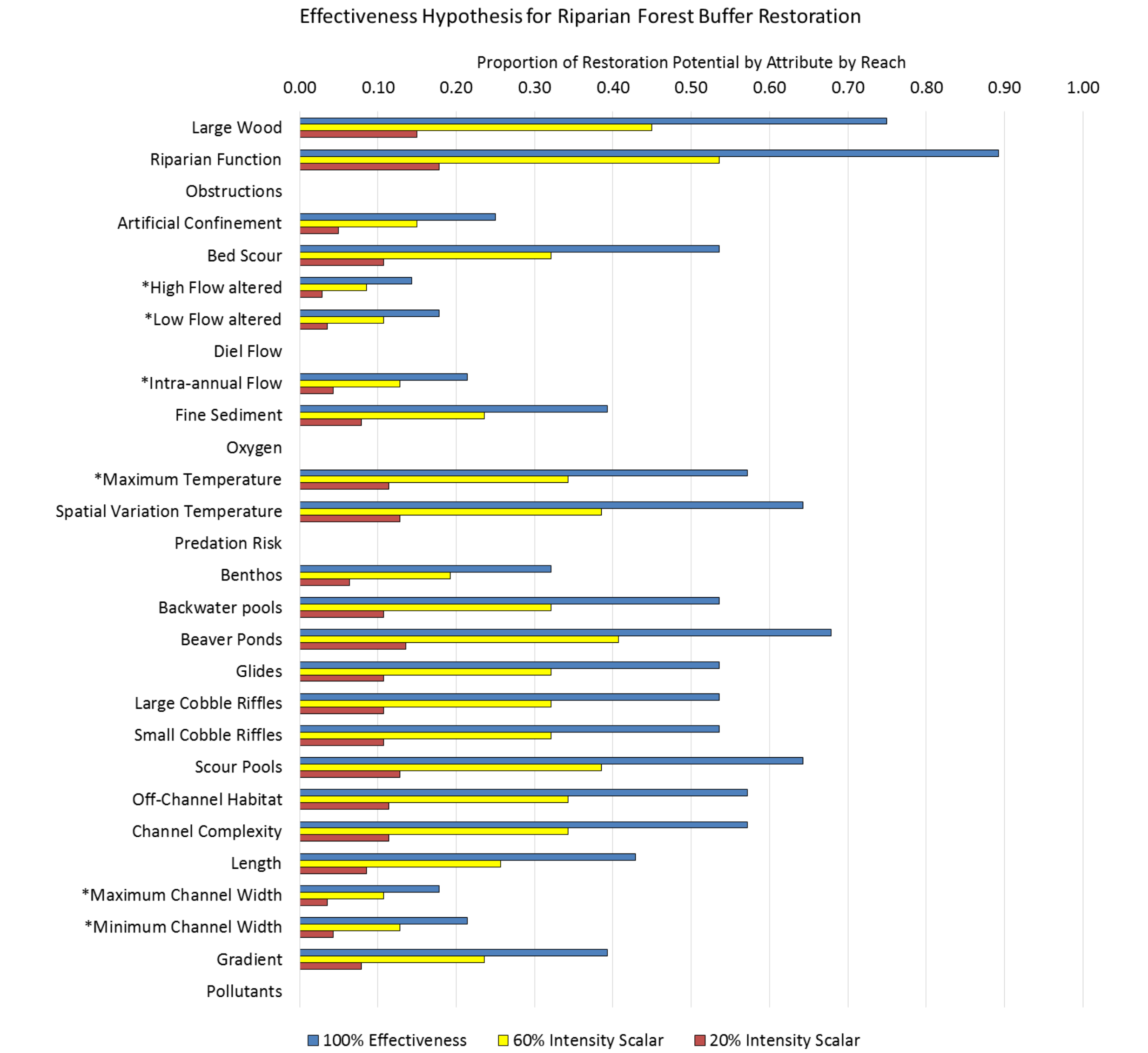


Figure A-20
Conceptual Model of the Effectiveness of Riparian Forest Buffer Restoration on Attributes in the EDT Model



Note:
This figure also shows the application of 20% and 60% intensity scalars used to define the restoration treatment in the ASHA alternatives.

Figure A-21
Conceptual Model of the Effectiveness of the FRFA Facility on Attributes of the EDT Model Downstream of the Facility

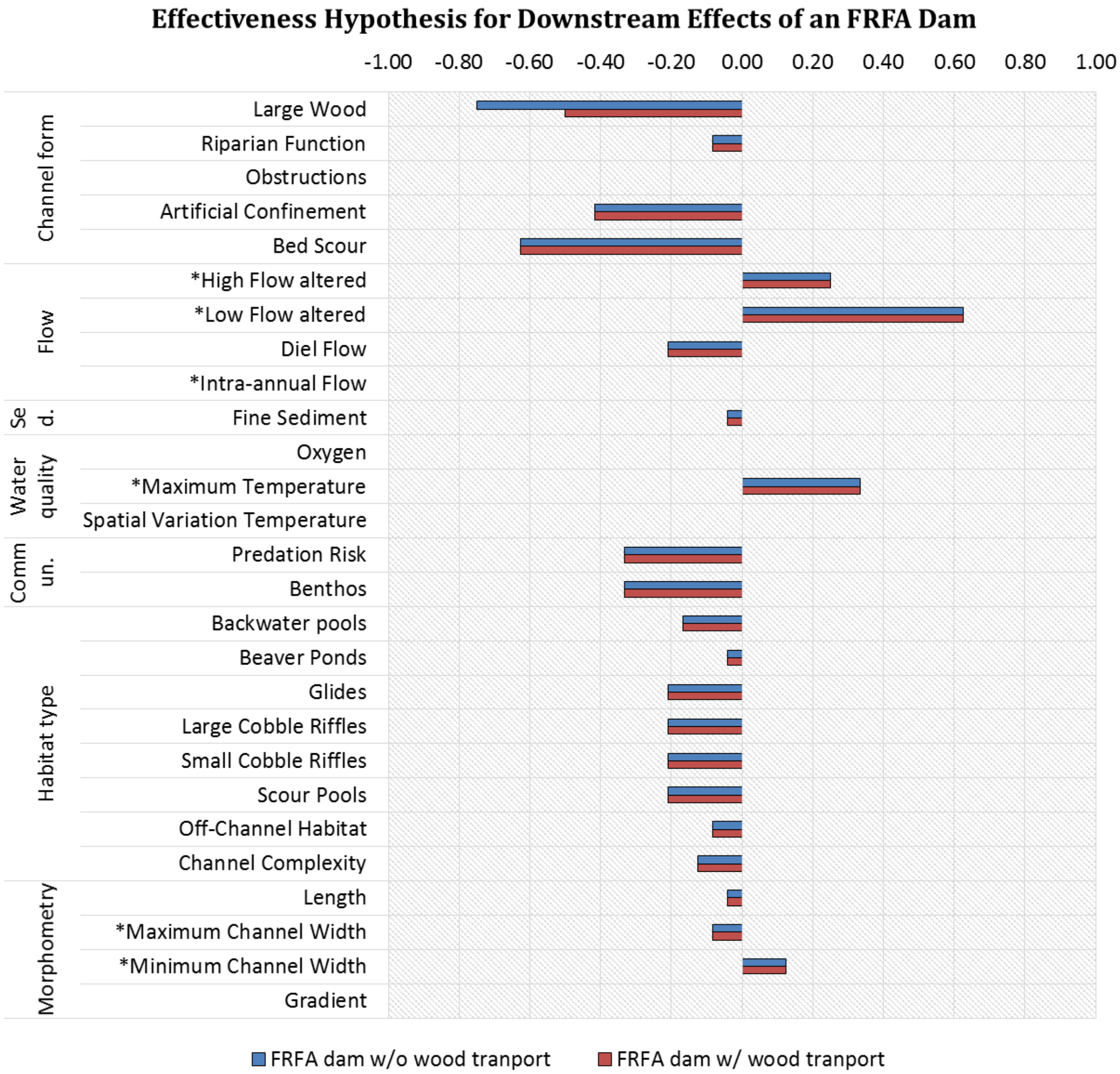


Figure A-22
Conceptual Model of the Effectiveness of the FRO Facility on Attributes of the EDT Model Downstream of the Facility

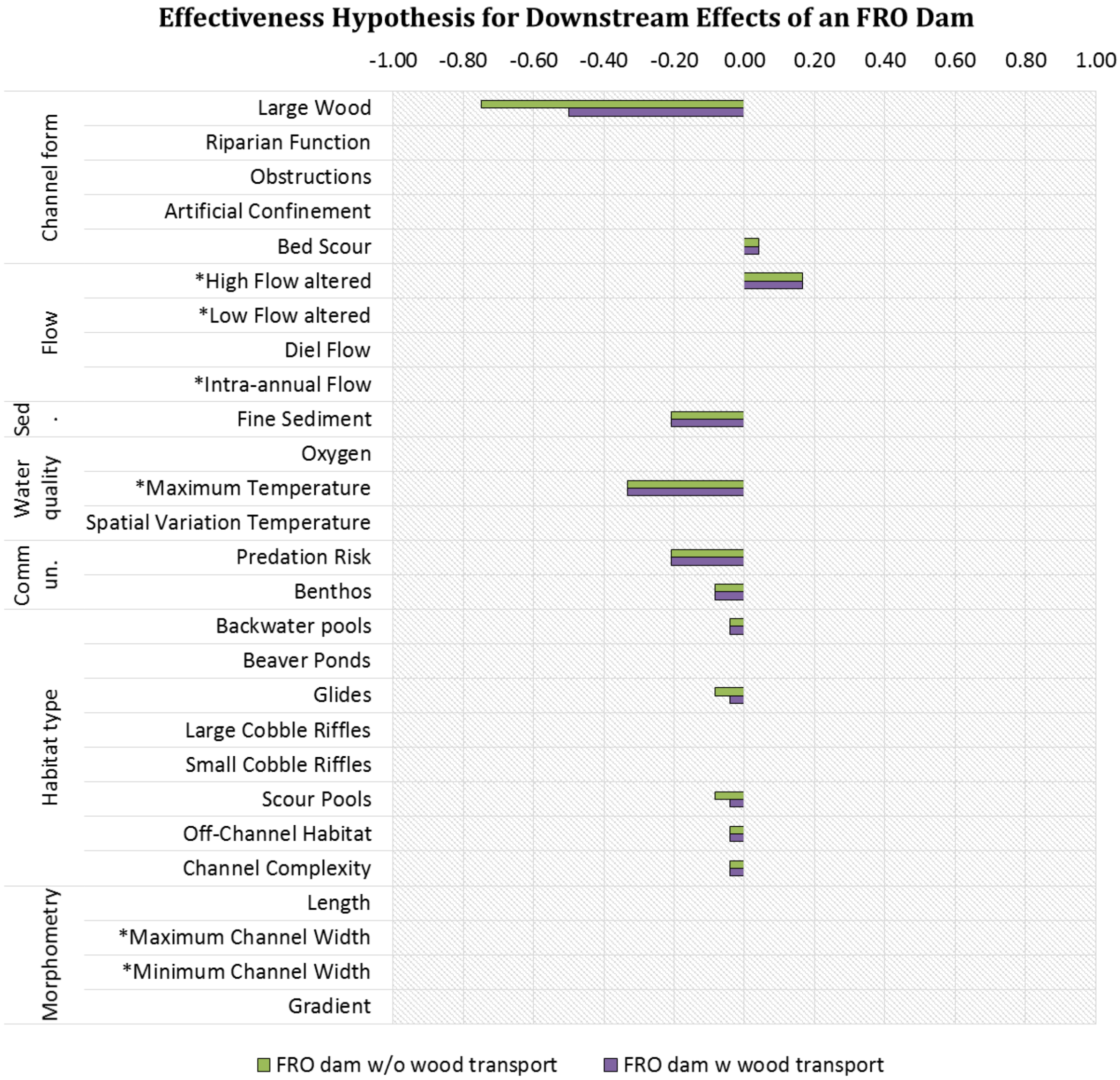
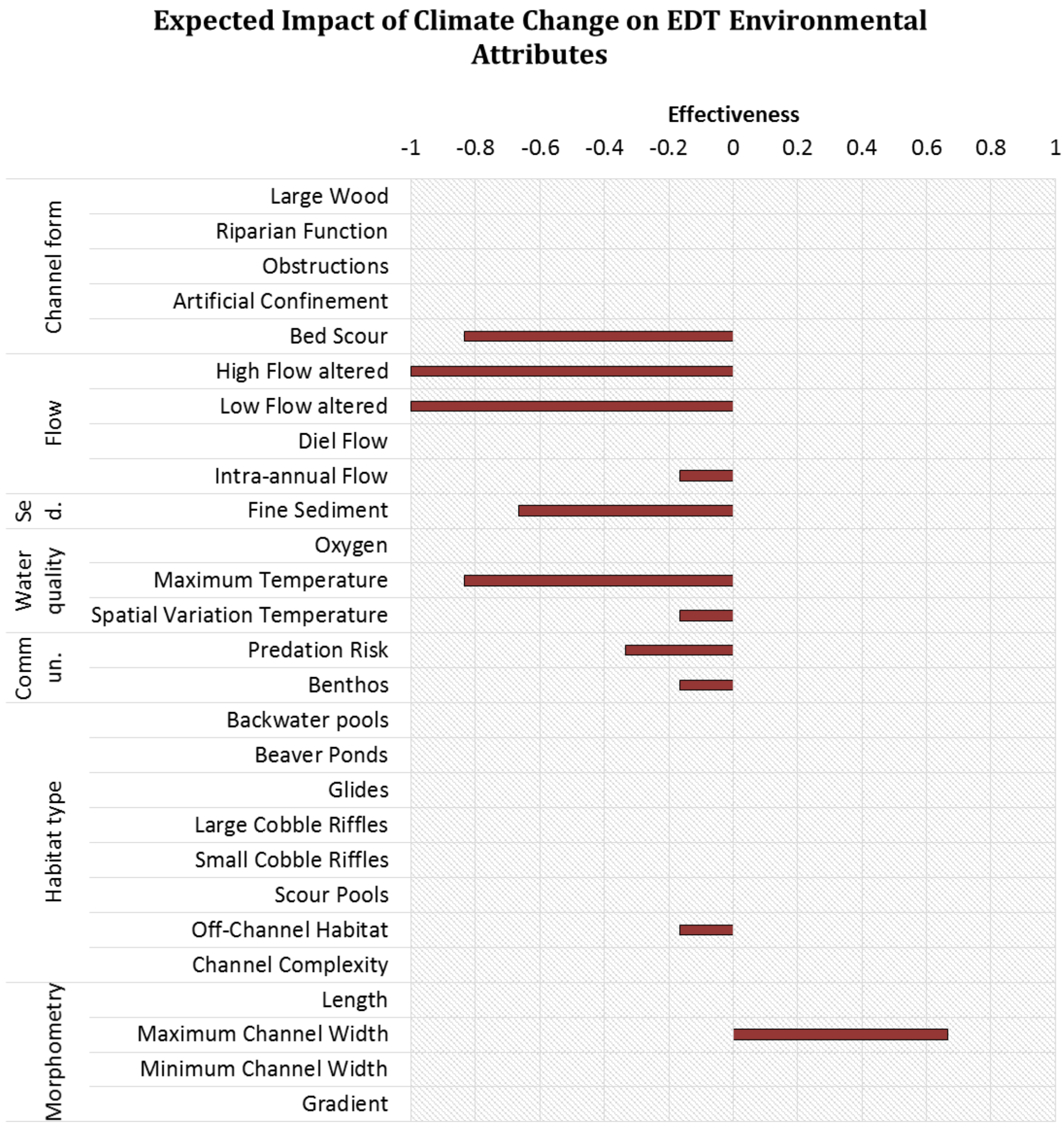


Figure A-23
Conceptual Model of the Effectiveness of the Future Climate on Attributes in the EDT Model



Intensity Scalar. The intensity scalar is used to adjust the effectiveness of a restoration action to account for situations that prevent achievement of the theoretical maximum amount of change in environmental conditions. There are many reasons why the theoretical maximum change cannot be achieved during actual restoration of specific sites. There may not be funds or opportunity for full restoration of a reach or there may be uncertainty regarding the scientific effectiveness of the action category. For these reasons, the effectiveness can be adjusted by applying the intensity scalar. For example, if a specific project proposed to restore riparian forest along 5 miles of a 10-mile reach, the ability of restoration to change the condition of an attribute at a reach scale could be estimated by multiplying the effectiveness values in Figure A-20 by an intensity scalar of 0.50.

Application in the PEIS. In the PEIS, the effectiveness values for the ASHA derived by the expert panel (Box 4) were scaled by intensity scalar values of 20% and 60% to create two alternative outcomes of riparian restoration in selected reaches throughout the Chehalis Basin (Figure A-20). This range of adjusted effectiveness for riparian restoration was combined with two alternatives for selecting reaches for restoration to create the Low Restoration and High Restoration scenarios for the ASHA. The two intensity scalar values were applied to the theoretical effectiveness values in Figure A-20 to create a range of possible outcomes of riparian restoration in the reaches selected for restoration in both the Low and High Restoration scenarios. This range captures both the uncertainty of implementation of restoration in the selected reaches as well as uncertainty in the effectiveness of restoration. The range of riparian restoration outcomes provided by the intensity scalars also serves as the basis for computing restoration costs for the Low and High scenarios.

6.3 Computation of the Adjusted EDT Ratings

To capture the effect of an action such as riparian restoration on stream reaches in the Chehalis Basin, the current rating for the attributes in the conceptual models was adjusted by decreasing the restoration potential of the attribute in each by the product of effectiveness and intensity. In other words, the procedure is as follows.

$$\textit{Revised Rating}_{arm} = \textit{Current Rating}_{arm} - (\textit{Restoration Potential}_{arm} \text{ X } \textit{Effectivenss}_{a} \text{ X } \textit{Intensity}_{rm})$$

where the subscripts designate an attribute (a), reach (r) and month (m).

The result for a restoration action that improves conditions is to decrease the Current rating and move the condition toward the Historic rating (Figure A-17).

This procedure was used to capture change for all attributes for which quantitative models were not available. This includes large wood and riparian function. Change in attributes related to flow (including maximum channel width) and temperature were computed from quantitative models (Figure A-2).

7 EDT GLOSSARY

Abundance: The number of adult fish returning to spawn in a population. Abundance is one metric of the VSP concept. EDT computes the equilibrium abundance of the Beverton-Holt function as a function of the quantity and quality of habitat. See also: equilibrium abundance.

Anthropogenic constraints: Constraints on a fish population that are caused by human alterations to the environment.

Bank full width: The wetted width of a stream when the surface of the stream reaches the top of the banks.

Behavioral plasticity: The ability of salmon populations to modify their behaviors in order to compensate for changing environmental conditions change.

Benchmark density: The maximum density (in fish per square meter) that the EDT model allows for any given life stage.

Benchmark survival: The maximum density independent survival rate that the EDT model allows for any given life stage of a species.

Beverton–Holt production function: A mathematical relationship used in EDT between the number of spawning fish and their resulting progeny. The two parameters to the Beverton–Holt function are capacity and productivity. The relationship is disaggregated in EDT to relate fish in one life stage to surviving fish in the subsequent life stage.

Biological diversity: Biological diversity is the range of morphological and behavioral variation within a salmon population generally related to genetic diversity. EDT calculates a habitat analog to biological diversity based on the variation in fish production across the variation in habitat (see Diversity). Biological diversity is an output parameter in EDT and is one of the metrics of the VSP concept.

Capacity: The maximum number of fish at a population or life stage, on average, that can be supported by a given set of environmental conditions, measured by the number of individuals. Capacity is one of the two parameters to the Beverton–Holt production function. In a Beverton–Holt stock-recruit graph, capacity is the horizontal asymptote.

Density-independent survival: The inter-generational survival of a salmon population in the absence of competition for space or resources measured as the ratio between spawners and progeny. In a Beverton–Holt model, the productivity parameter is calculated as the product of density-independent survival and eggs per spawner. Survival is an intra-generational parameter that describes the proportion of individuals within a cohort that survive from one life stage to the next, or from egg incubation to spawning.

Diagnostic unit: A spatial scale in the Chehalis EDT model that is composed of at least one, but generally several, reaches to form an ecologically useful component of a stream (e.g., the South Fork of the Newaukum River Diagnostic Unit).

Diversity: An index of biological diversity of life histories potentially expressed by a population in EDT as a function of the spatial and temporal diversity of suitable habitat. Diversity is the proportion of life-history trajectories that have a productivity greater than 1.0 in a particular environmental condition.

Effectiveness: Restoration effectiveness is a scalar indicating how effective a particular type of restoration project is at restoring historic habitat conditions. The scalar is a number in the range 0 to 1, with 0 indicating that an action is totally ineffective at restoring historic habitat conditions and 1 indicating that an action can completely restore historic habitat conditions.

Equilibrium abundance: The number of individuals in a salmon population where the ratio between spawners and progeny is exactly one. In a Beverton–Holt production function, equilibrium abundance is calculated from productivity and capacity using the formula $N_{\mathrm{eq}} = C \times (1 - P^{-1})$. In a Beverton–Holt stock-recruitment graph, the equilibrium abundance is the point at which the line $y = x$ intersects the stock-recruitment curve.

Environmental attributes: Fundamental physical and biological features of the environment that form the Basin input to EDT and are entered as ratings (see Ratings). Examples include water temperature, flow, and quantity of large wood. Survival resulting from one or more environmental attributes is merged in EDT as Survival Factors.

Estuary/Estuarine: The transitional environment between the freshwater riverine environment used by juvenile salmon and the saltwater environment of the ocean. Estuarine environments are characterized by brackish water (intermediate between fresh and salty) and by tidally driven flow patterns.

Habitat heterogeneity: The degree to which habitat conditions vary spatially and temporally within a river basin.

Habitat quality: Environmental attributes describing the quality of habitat available to a salmon population that affect survival and capacity in EDT. Examples include temperature, substrate, and large wood.

Habitat quantity: Environmental attributes describing the quantity of habitat (square meters) available to a salmon population. In EDT, habitat quantity attributes are used to calculate capacity.

Intensity: Restoration intensity is a scalar on the implementation of a restoration project relative to the target habitat. The scalar is a number in the range 0 to 1, with 0 indicating that a restoration project's footprint has no overlap with the target habitat, and 1 indicating that a restoration project's footprint overlaps with the entire target habitat.

Intrinsic conditions: The condition of a watershed in the absence of anthropogenic constraints on salmon performance. Intrinsic conditions include factors such as geomorphology and historical climate.

Life history periodicity: The time of the year when each life stage of a salmon life history is present in a river system. For example, spring-run and fall-run Chinook salmon are characterized by a different periodicity: Spring-run adult migrants enter the river in the spring-run and hold over the summer, whereas fall-run adult migrants enter the river in the fall-run.

Limiting factor: See Survival factor.

Normative condition: The condition of an ecosystem with a mix of natural and cultural features that allows the expression of a diverse and sustainable suite of desirable species and populations. The normative condition is not equivalent to the historic condition nor is it generally the current condition of most systems, but is one in which natural ecosystem functions are allowed to shape the system in the context of human cultural activities.

Obstruction: A physical structure through which a stream flows, such as a culvert, weir, or dam, that blocks or reduces upstream or downstream fish migration.

Ocean-type life history: A salmonid life-history category characterized by downstream migration of juveniles to the ocean in the same year that they emerge from egg incubation, generally in the first spring-run. They do not overwinter in freshwater as juveniles. This contrasts with stream-type life history.

Productivity: The ratio between the number of recruits in a cohort and the number of recruits in the previous cohort in a salmon population without the effect of competition for space or resources. Productivity is one of the two parameters to the Beverton–Holt production function. It is also one of the metrics of the VSP concept used as output from the EDT model. Productivity is calculated by multiplying the density-independent survival by the number of eggs per spawner.

Progeny: The number of adult fish produced by a given number of adult spawners. See Recruits.

Protection: The value of habitat to the current level of production and a measure of the impact of degradation of current conditions on current habitat potential.

Rating: Input data to EDT for most habitat quality attributes. Empirical and other data are standardized to a 0 to 4 scale that relates to the degree of degradation of life stage benchmark survival as a result of observed conditions in a reach. These ratings are defined on a 0 to 4 scale, with 0 meaning very favorable habitat conditions and 4 indicating very unfavorable habitat conditions.

Reach: A section of a river or stream that is used as EDT's most basic data management unit within which conditions are assumed to be homogeneous and defined by habitat quality and quantity ratings. Reaches are generally defined by geomorphic characteristics or by obstructions.

Recruits: The number of adult spawners that are the progeny of a previous cohort of spawners.

Restoration: The potential of habitat to increase fish abundance when conditions are restored to historic conditions.

Returns: The abundance of fish returning to a watershed.

Spatial structure: The distribution of populations of fish across a watershed (e.g., the Chehalis Basin) or other geographic delineation. Spatial structure describes the distribution of productive habitat across the area. In the Chehalis analysis, spatial structure refers to the distribution of production across sub-basins of the Chehalis Basin. Spatial structure is one of the metrics of the VSP concept used as output from the EDT model.

Spawners: Adult salmon that are digging redds and laying and fertilizing eggs.

Splice: An EDT model run in which the environmental conditions for a specific geographic area (reach, diagnostic unit, sub-basin) are changed in order to measure the sensitivity of the salmon population to conditions in that area. Splicing degraded river conditions into current river conditions is used to identify protection priorities. Splicing historic river conditions into current river conditions is used to identify restoration priorities.

Stock–recruitment relationship: A mathematical model describing the relationship between the number of individuals in a cohort of salmon and the number of individuals in the previous cohort. See Beverton–Holt production function.

Stream-type life history: A salmonid life-history category characterized by extended rearing in freshwater for the year following emergence from egg incubation. Stream-type fish overwinter in freshwater and migrate to the ocean the following spring-run.

Sub-basin: A tributary sub-watershed that drains to the main Chehalis River (e.g., the Newaukum sub-basin).

Survival: An intra-generational parameter that describes the proportion of individuals within a cohort that survive from one life stage to the next, or from egg incubation to spawning after experiencing the effect of one or more survival factors.

Survival factor: Physical parameters affecting the survival of a particular life stage often referred to as limiting factors. Examples include flow, sediment, or temperature in EDT that are computed from relationships with one or more environmental attributes. The product of all EDT survival factors with the benchmark survival is the total survival for the life stage.

Template: EDT terminology for the watershed-specific reference condition that is used to diagnose the current condition in a watershed. In the Chehalis analysis, Template is equivalent to the intrinsic condition of the watershed absent anthropogenic constraints. Template conditions were determined from reconstructed historical conditions.

Thalweg: The part of a stream with the greatest depth and greatest flow velocity.

Trajectory: A life-history pathway of a fish population consisting of a spatio-temporal sequence of life stages arrayed across the riverscape. Each trajectory may vary in direction, rate of travel, and timing of life stages.

Viable salmonid population: A Viable Salmonid Population (VSP) is "an independent population of any Pacific Salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame" (McElhany et al. 2000). VSP metrics that describe the viability of fish populations are abundance, productivity, biological diversity, and spatial structure. EDT uses the VSP metrics to describe potential fish production as a function of habitat.

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